ANNALS

OF THE

Association of American Geographers

VOLUME XIII — JUNE, 1923 — No. 2

SOILS OF THE GREAT PLAINS

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INTRODUCTION.—The Great Plains, as defined in this paper, is a region in which certain soil characteristics prevail. No attempt whatever is made, in this definition of the region, to conform to any of the other definitions that have been proposed or used. The paper is written for the purpose of describing the soils of the region and for that reason soil character will be given the predominant attention

not only in the details of descriptions but in the definition and delimitation of the region.

THE GENERAL FEATURES OF THE SOIL.—The Great Plains, thus defined include that part of the United States, lying east of the Rocky Mountains, in which the soils are characterized, at maturity of development by (1) the presence, on some horizon of the soil section or profile, of a zone of alkaline salt accumulation, usually, not exclusively, lime carbonate and (2) a relatively dark colored surface soil. The color varies, from place to place, in degree of darkness but throughout the region it is darker than the mature soil in any other part of the country in which the zone of salt accumulation is present in the soil.

These are the two characteristics that are universally present in the soils of the Great Plains. Neither can be accepted as an exclusive characteristic taken alone since the dark color of the soils, even of mature soils, is present in regions far beyond the limits of the Great Plains where the salt zone is not present and, on the other hand, the salt zone is present in large sections outside the area of the Great Plains but the dark color of the surface soil is lacking.

The dark color of the soil extends several hundred miles east of the eastern boundary of the Great Plains while the presence of the salt zone extends far west of the region in which the soils are dark in color. The two characteristics therefore are not coincident in their distribution, the one extending eastward beyond the area in which both are present and the other extending westward beyond the same area. The region in which the two overlap is designated as the Great Plains.

The position of the Rocky Mountains, along the western boundary seems to be accidental, it being apparent that the western boundary would lie about where it is if the Rocky Mountains were not in existence. This is suggested by the fact that the mountains do not everywhere form the boundary and where absent there is no important deviation of the line from the general course taken by it in places where they are present.

THE BOUNDARIES OF THE GREAT PLAINS.—*The Eastern Boundary.*—Since a dark surface soil is characteristic not only of the soils of the Great Plains, but of an extensive region east of the Great Plains, it is evident that the eastern boundary of the region must be determined on the basis of the other characteristic of the Great Plains soils,—the zone of carbonate* accumulation. Since the Great Plains region as defined, does not extend east of the area in which the zone of carbonate

* Since the zone of salt accumulation is so predominantly a zone of carbonate accumulation, the latter expression will be used hereafter in this paper and the reader should understand also that it means in practically all cases a zone of lime carbonate accumulation.

accumulation is present it is evident that the eastern boundary is also the boundary of the zone of carbonate accumulation.

Since nature rarely establishes sharp boundaries, and since man must usually do so, we define the eastern boundary of the Great Plains as the line along which the zone of carbonate accumulation, universally† present throughout the Great Plains, disappears entirely or becomes so faintly developed that it cannot be identified by ordinary field observation. The zone may be very faintly developed in favorable localities east of the line here described.

Beginning at the northern boundary of the United States, the eastern boundary of the Great Plains enters the country from Canada a few miles east of the northwestern corner of Minnesota, runs thence southward by Alexandria and Big Stone Lake, Minnesota, approximately along the South Dakota-Minnesota boundary to the southern part of the State, cuts off the southeastern corner of South Dakota, passes within a few miles of Norfolk, Nebraska and about 20 miles west of Lincoln, entering Kansas a few miles east of Mankato. It continues thence southward running some 20 miles east of Pratt, Kansas, passing in the vicinity of El Reno, Oklahoma, Henrietta and Olney, Texas to the vicinity of Baird, Texas. It crosses Coleman County, Texas in an irregular line running in places eastward into Brown County, runs east of Brady, crosses the Edwards Plateau not far from Mason and Fredericksburg, thence through San Antonio and Beeville to Corpus Christi. (Fig 1)

The Western Boundary.—It has been stated above that the Rocky Mountains bound the Great Plains on the West. This is in general true, but, as has already been stated, they seem to be more or less accidentally situated along the western boundary since this line would be, in part at least, where it is if the mountains did not exist. The western boundary where the mountains do not fix it, must be established on the basis of soil color, since the other soil characteristic of the Great Plains, the presence of a zone of carbonate accumulation, extends westward far beyond their western boundary. The western boundary therefore lies along that line or zone which divides the dark colored soils of the Great Plains from the light colored soils of the region west of the Great Plains, leaving the mountains out of consideration.

† To say that the salt zone is *universally* present in the soils of the Great Plains is not strictly correct nor would it be strictly correct to state that all animals of the Jersey cattle breed have horns. They do not have horns until they have attained a certain stage in their development. In the same way the *undeveloped* or *immature* or *young* soils of the Great Plains do not have a zone or horizon of lime carbonate anywhere in the soil section. It is present only in those soils that have attained a stage in their development that would correspond in organic beings to the stage described as mature. To be strictly accurate therefore the phrase should run somewhat as follows: Universally present *in the mature soil* throughout the Great Plains.

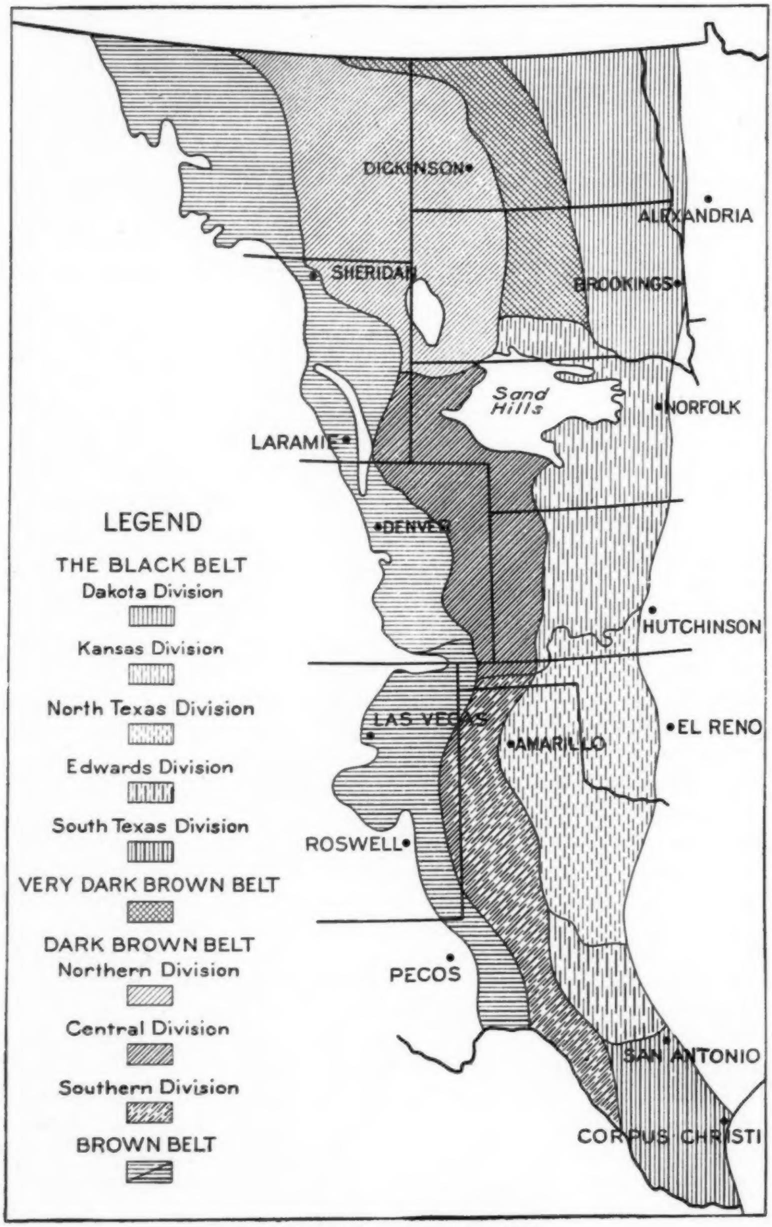


Fig. 1. Soil Map of the Great Plains

In the northern section the eastern foot of the mountains forms the western boundary of the Great Plains from the Canadian boundary southward by Helena, Whitehall, Livingston and Red Lodge, Montana, Sheridan and Buffalo, Wyoming. From the south end of the Big Horns to the mountains southeast of Rawlins, Wyoming. the boundary does not coincide with the mountain base. South of that point it follows the Rocky Mountain front by Denver, Colorado Springs and Trinidad, Colorado, Raton and Las Vegas, New Mexico. Thence to the Rio Grande it does not follow a mountain chain. The mountain range, south of Las Vegas, New Mexico, is broken up into isolated mountains.

Where the boundary would be, along the northern line of the United States, if the mountain range were not present, cannot be stated definitely. It is true however, that west of the mountains, a region of importance, both in size and value from the point of view of productive capacity, is essentially identical in soil character, and in many other features as well, with the Great Plains. This is the well known Palouse region in eastern Washington and eastern Oregon. While this is however a region identical with the Great Plains in soil character, yet it cannot be considered as a part of that region cut off from the main body by the mountains. This is evident from the details of its features. It is not a continuation of the Great Plains but another Great Plains in miniature and will have to be considered as an independent region due to local conditions. If the mountains were not present it would not exist, but its place would in all probability be occupied by gray desert soils.

The western boundary of the Great Plains proper, were the mountains not present, would lie, somewhere between the eastern and western mountain fronts, probably not far from the eastern.

In the stretch between the south end of the Big Horn range and the north end of the Colorado ranges, southeast of Rawlins, the western boundary of the Great Plains runs southward without significant divergence from its course along the Big Horns. The Laramie range is a feature lying within the Great Plains like the Black Hills of South Dakota, the several ranges surrounding the Judith Basin and other isolated mountains in Montana. West of Caspar and Sussex, Wyoming, the soils become too light in color in a short distance for this section to be included in the Great Plains.

South of Las Vegas the line as placed on the map swings westward and southward but swings back across the Pecos a short distance north of Roswell, New Mexico, turning south along the east side of the stream reaching the Rio Grande west of Sanderson, Texas.

There are a number of areas west of the Great Plains that have Great Plains characteristics. They are all isolated, none of them being continuous with the Great Plains, and all are due to local conditions. An important area of this character covers the highlands of New Mexico from a few miles west of Socorro to, and beyond, the Arizona boundary. It is a narrow belt, just north of the forested area which lies on the watershed separating the southward drainage, mainly to the Gila, from the northward drainage, mainly that of the Little Colorado, and the desert country to the north. Other areas, with more or less definite Great Plains characteristics occur throughout the mountain region of the west.

The western boundary of the Great Plains therefore, for a considerable part of its stretch, is accidental, formed by what, from the soil point of view, is the accident of mountain building. That this is accidental and that the region would have had a western boundary that could have been defined in terms of soil characteristics is shown by the fact that such a western boundary is actually present where the mountains do not exist.

THE SOIL BELTS.—The soils of the Great Plains are uniform to the extent, as has been pointed out already, that they are dark in color and are underlaid by a zone of lime carbonate accumulation Fig. 1. They differ however in the degree of darkness of the soil color from place to place and in the depth as well as in other minor characteristics of the carbonated zone. The change in color and the change in depth to the zone of carbonate accumulation are complementary; as the color decreases the carbonate zone rises and *vice versa*.

Since the soil color is a surface feature, and more easily and directly open to observation than the other, it is more convenient to use the change in color as a basis for the subdivision of the soils of the region into soil subgroups, these being further subdivided into areas. There is a progressive decrease westward in the darkness of the soil color. This is true regardless of the latitude on which the examination is made. The color changes somewhat from north to south also as will be shown below, but in all latitudes the color along the eastern boundary has a maximum degree of darkness for the particular latitude selected with a minimum degree along the western boundary.

The region as a whole may be readily divided into three north-south belts of soil, on the basis of the darkness of soil color, which we may designate as (1) the Black Belt, (2) the Dark Brown Belt, and (3) the Brown Belt, and for the northern end of the region it is convenient to insert a Very Dark Brown Belt between (1) and (2). The general distribution of these belts, so far as existing knowledge will permit its mapping, is shown on the map (Fig. 1) and needs no description. It is

shown in a somewhat diagrammatic way, as though the belts were continuous and unbroken from one end to the other. This is done in order to give them clear expression. Certain minor modifications are details, some of which will be located and described later in the paper.

The Black Belt.—The Black Belt seems to be the equivalent of the Black Earth or Chernozem of the Steppes in European and Asiatic Russia. The soil is black, or is the darkest of the Great Plains soils, and the carbonate zone lies, in the United States, at a depth ranging from 2 to 5 or 6 feet. Not only does the surface soil have a maximum of darkness but the thickness of the dark colored horizon is a maximum, ranging in the normal soil from about 8 or 10 inches to about two feet. While these general characteristics prevail throughout the whole belt, there is considerable variation in them in detail, and certain minor characteristics present themselves in the different parts of the belt.

On the basis of soil characteristics the Black Belt may be subdivided into five areas or divisions which may be designated as (a) The Dakota Division (b) The Kansas Division (c) The North Texas Division (d) The Edwards Division and (e) The South Texas Division.

The Dakota Division.—The Dakota Division occupies the northern end of the belt. Its area and extent are shown on the map (Fig. 1). The soils in this division are blacker and the dark colored horizon is in general thicker than in the other divisions. The carbonate zone, taken as a whole is shallower than in the other areas, except possibly in the Edwards Division.

Very little attention has been given to the details of the soil profile, especially as regards the structure of the soil. In the northeastern part of the area the soils, being developed from lake deposits, are rather heavy in texture over large areas. Around the borders of the section of heavy soils, the basin of the extinct Lake Agassiz, however, there are considerable areas of sandy deposits which have developed into sandy soils. On the rolling uplands of the rest of the state, underlaid by glacial drift, the predominant textures are loams and very fine sandy loams. In the James River valley there are large areas of smooth lands underlaid by gravel beds within a few feet of the surface, though the soils above the gravels are usually loams. Sand areas lie irregularly distributed over the whole region but do not form any considerable part of it.

The shallow depth at which the carbonate zone has formed is possibly due mainly to the highly calcareous nature of the parent glacial drift from which the soils have developed. It seems that a high percentage of lime carbonate in the parent material causes the formation, at

an early stage in soil development, of a carbonate zone at a shallow depth; this is later driven downward as leaching progresses until equilibrium has become established in accordance with the rainfall,—this final position being wholly independent of the character of the parent rock. It seems probable that the reason the soil in this division is darker than in the others is due, in part at least, to the same highly calcareous parent rock. Soils developed from calcareous parent rocks, at a certain early mature or still earlier stage of development are universally darker in color than the same soils in a later stage of the cycle. It seems probable therefore that these soils are now in that early stage of development in which the calcareous parent rock expresses itself effectively in the color of the soil. Such soils are well known elsewhere. The Black Soils in the Black Belt of Alabama and Mississippi are of this character; so also are the "Black Waxy" soils of Texas. These black soils of Texas, Alabama and Mississippi lie in a region in which the well matured soil is light in color and when these black soils finally become mature they will, presumably, assume the characteristics of the mature soils of the region in which they lie. The North Dakota soils however lie in a region in which the normal or mature soils are dark in color and when in their development they assume the normal color of the soils of the region they will not become light in color. Indeed they will not be essentially different in color from what they now are, since the normal soils of the region are black. They will lose their *local* black color and assume a *regional* black color.

Soils that are black due to the persistence of the influence of a calcareous parent rock are known as *Rendzinas,* a term applied by Polish peasants to the limestone soils of Poland. The soils of the Dakota Division seem therefore to be half Rendzinas and half Chernozorus, but as they develop they will gradually lose their Rendzinas characteristics and assume more and more the characteristics of true Chernozorus. Since the soils of both groups are black the change will not be a noticeable one. The main change that will take place will be the gradual downward movement of the carbonate zone, finally halting at a depth of from 3 to 5 feet.

In parts of this region, in Beadle County, South Dakota especially, a soil, with a profile varying markedly from the typical profile of the region, extends over a considerable area. The variation is a feature of the subsoil and consists of the presence of a heavy, tough, usually dark colored horizon, varying from six inches to a foot or more in thickness, lying beneath the soil and above the rather heavy but not tough shaly glacial drift. Its presence seems to be due to the presence

of sodium salts in small amounts in the soil water, causing a deflocculation of the surface soil, a washing downward of the deflocculated clay particles and a refloculation and accumulation of these particles in the subsoil due to a change in composition of the salts. The amount of salts present is not sufficient to cause injury to growing plants but the heavy subsoil is somewhat unfavorable to plants because of its influence on the amount and availability of the subsoil moisture. The total thickness ranges from 10 to 20 inches.

The Kansas Division.—The Kansas Division lies south of the Dakotas, its location and extent being shown on the map (Fig. 1). A typical profile or section of the soil in this area is about as follows: 1. Grayish black to black horizon, showing a horizontal arrangement of particles but not stratification and with no noticeable granulation, the thickness varying from a mere film to about 5 inches. (Not always present.) 2. Black to grayish black, highly granular horizon very little heavier in texture than No. 1, ranging from 8 to 18 inches in total thickness. 3. Dark gray to gray, heavy horizon, somewhat granular at top but losing the granulation in a few inches, with a very marked capacity for breaking into vertical columns of 2 to 3 inches in diameter where exposed in banks. 4. Yellowish brown horizon, often breaking on drying into small vertical columns. This horizon is not always present. It ranges up to 6 inches in total thickness. 5. Gray, loose, friable horizon, highly calcareous. The carbonate zone. 6. The parent geological formation which may range from loose, through glacial drift to the disintegrated material from various sedimentary rocks. (Pl. I. a.) Horizon 3 is sometimes absent especially on the rolling lands and in these cases horizon 4 is likely a foot or more thick.

The carbonate horizon lies at greater depth in the soils of this division than in those of the Dakota division. The soils seem to have become more maturely developed and the carbonate horizon to have reached a stable depth. The heavy horizon (Pl. I. c) is developed on the flat lands throughout the region but is not everywhere equally heavy. It seems to be characteristic of a larger area in Nebraska than in Kansas and seems also to be better developed, other things being equal, in the eastern part of the area than in the western part.

The color of the soil is less black than in the Dakota region and it is also less black than is the Black Earth of Bessarabia and parts of Roumania. It seems to be more like that of the dark colored soils of the Hungarian plain and the better parts of the Plains of Thessaly in Greece. The color is grayish black rather than the dense coal black of the soil in Moldavia, Roumania. The grayish shade seems

to be as characteristic of the soil in the eastern part of the area as in the western, differing seemingly in that respect from the same soils in European Russia.[1]

The Kansas Division is a region with agricultural characteristics as well defined, taken as a whole, as are those of the Dakota Division. The latter is the region of predominant spring wheat, this is the region of predominant winter wheat. The extreme northern portion of the area has a climate a little too severe for a perfectly safe winter wheat agriculture and is a little too far south for spring wheat. Corn assumes an importance equal to wheat but in the greater part of the area winter wheat is not only the predominant, but almost the only crop.

The North Texas Division.—The location and extent of this division, which includes portions of Kansas, Oklahoma and Texas are shown on the map (Fig. 1.) A typical profile in the northern part of the area is about as follows:

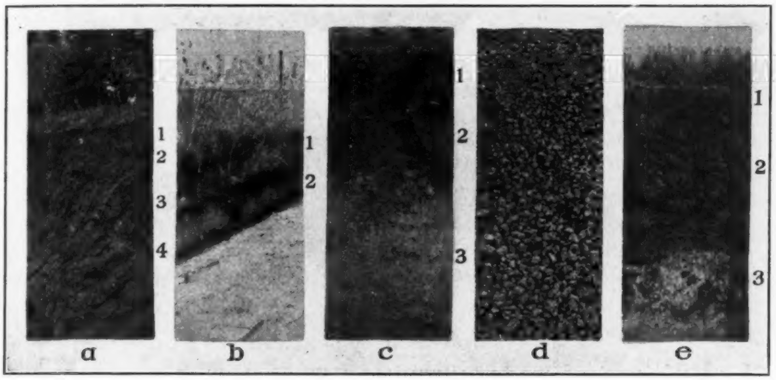
Soil Profile at Stamford, Texas.—(Pl. I, c, d,e).

1.	Dark brown loam with reddish shade.........	0 to 10 inches
2.	Reddish brown clay loam, granular...........	10 to 18 inches
3.	Pinkish highly calcareous clay loose..........	18+ inches

These profiles differ from that of the Kansas Division in several respects: The soil as a whole is not so dark in color. The highly granular subsurface horizon is not so well developed as in the Kansas Division; the heavy, cloddy horizon with columnar breakage,—so well marked as No. 3 in the Kansas profile is less well developed here; a reddish brown color which was not present in the Kansas section becomes well defined in the subsurface; the reddish or pinkish color persists into the carbonate horizon in the North Texas Division; and the carbonate horizon becomes much more highly calcareous, with sharper upper boundary, than in the Kansas Division. The dark color of the surface soil and the carbonate zone are the two features that are common to all the divisions described so far. The granular horizon is present in the North Texas area; it is merely somewhat less pronounced in its development than further north. The change from the characteristics of the Kansas area to those of the North Texas area takes place gradually.

Certain characteristics of soil development. It becomes necessary at this point to turn aside to discuss briefly a feature of soil development under certain conditions of environment which has a pronounced influence on the details of soil character and distribution.

[1] D. K. Glinka, Die Typen der Badenbilding, Berlin 1914, Page 116



a. Soil profile near Belleville, Kansas. Horizon 1, is the granular horizon; 2, the heavy cloddy imperfectly columnar horizon; 3, the brown finely columnar horizon; 4, the carbonate horizon. Kansas Division of the Black Belt.

b. Soil profile near LaCrosse, Kansas. Shows only the dark colored horizon and the carbonate zone. Kansas Division of the Black Belt.

c. Soil profile at Westover Texas, representing the North Texas Division of the Black Belt in a locality where the red color is not developed. Horizon 1 is the granular horizon, 2 the heavier, cloddy horizon and 3, the carbonate horizon.

d. Shows the granular structure of horizon 1 in c

e. Soil profile at Amarillo, Texas. Horizon 1 is the structureless horizon, (has probably been plowed); 2 a heavy clay, faintly columnar, horizon with imperfectly developed granular structure, and 3, the carbonate zone. North Texas Division of the Black Belt.

In every region, whatever its character, the soil passes through a series of stages in its development from what may be called its infantile conditions to a condition that may likewise be designated as old. The infantile condition is represented by that existing in the parent soil material immediately after it has been accumulated in the place where it is later developed into soil. The features assumed by the soil in its development from infancy through youth, maturity and old age vary with the environment, especially with the climate and the natural vegetation. The broad general features assumed by the normal or mature soil will be uniform throughout any given climatic and vegetational region.

In its youth the character of the soil is determined by that of the parent geological material. As it advances in stage of development, geological features become less and less influential and "acquired" characteristics become more and more influential as determinants of soil character. At what may be designated as the mature stage in its development the character of the soil is dominated by acquired characteristics and the characteristics determined by those of the parent rock have disappeared or become subordinate; and this relationship continues to exist thereafter, though becoming progressively more and more pronounced. In the infantile stage of development the soil varies according to the character of the parent material and has no necessary relation to the character of the climatic and vegetational region in which it occurs. The soil character will not vary with the latter conditions, but with the former only.

At maturity however the "accidental" hit or miss characteristics of the parent rock have disappeared from the soil or have become very subordinate to those gradually acquired during development so that throughout a given climatic region the broad general features of the soil will have become uniform. Maturity may be defined as that stage in the soil development where its dominant features are those accquired during development and not those determined by the character of the parent rock and in which these features have attained an average degree of development and in no feature have attained an abnormal degree of development. The normal degree of development will be that characteristic of the majority of the individual soils, in the given region, which have lost their infantile features.

The rate at which soil development takes place in any given climatic or vegetational region varies with the topography and the texture of the soil material. If the latter be very heavy the rate will be slow and if very light it will be rapid. Where the material is intermediate in texture, as is the case with most soil materials, the rate will be

strongly influenced by the topography. The soil will attain maturity on the flat and gently rolling surfaces earlier than on the rough, and in fact it may never attain full maturity on the latter. As development proceeds, erosion removes the changed surface material so that the soil is being perpetually rejuvenated and a new soil is continually being formed by fresh material accumulated from the rock below by disintegration, or by the soil section moving gradually and continually downward into fresh geological material.

The topography of the Dakota Division is constructional, the stream valleys are shallow and free from steep slopes. There are no important areas in which the topography is rough enough to interrupt the normal course and rate of soil development. All the soils are submature or younger; this being indicated in ascribing some of their dark color to the character of the parent material, but they are all alike in this respect. Rendzinas are young soils, wherever they may be found.

In the area of the Kansas Division the topography is not as uniformly free from steep slopes as in that of the Dakota Division, but a relatively small percentage of the total area is rough. These rough surfaces are covered by immature soils, in which the profile is not normally or maturely developed, yet the percentage of total area is small. On such slopes however, the only feature of the mature soil profile of the region that has been developed is the dark surface horizon, and this has usually but a fraction of its mature thickness. By far the larger part of the area is smooth, and this is covered by soils that have reached a mature or normal stage in their development. Rendzinas are not present on these smooth uplands.

In the North Texas area however, a much larger proportion of the total area is rough enough to prevent the attainment of maturity by the soil. This explains the character of the soils of the area as shown in the typical profiles already described. The climate of this region is different from that in Kansas in a subordinate but significant way and effects the course of soil development in the same direction as the topography and emphasizes the effect of that factor.

The special climatic features are the prevailing high temperature with a correspondingly rapid evaporation of moisture, and the occurrence of the rainfall in sudden heavy downpours of short duration.

The characteristic features of the mature soil in the North Texas area develop therefore only on the poorly flat lands and not on the rolling lands. A considerably smaller proportion of the total area is covered by mature soils than in the Kansas or Dakota divisions. The map (Fig. 2) will give some idea of the proportion of the total area that is covered by the mature soil, the Abilene clay loam. This

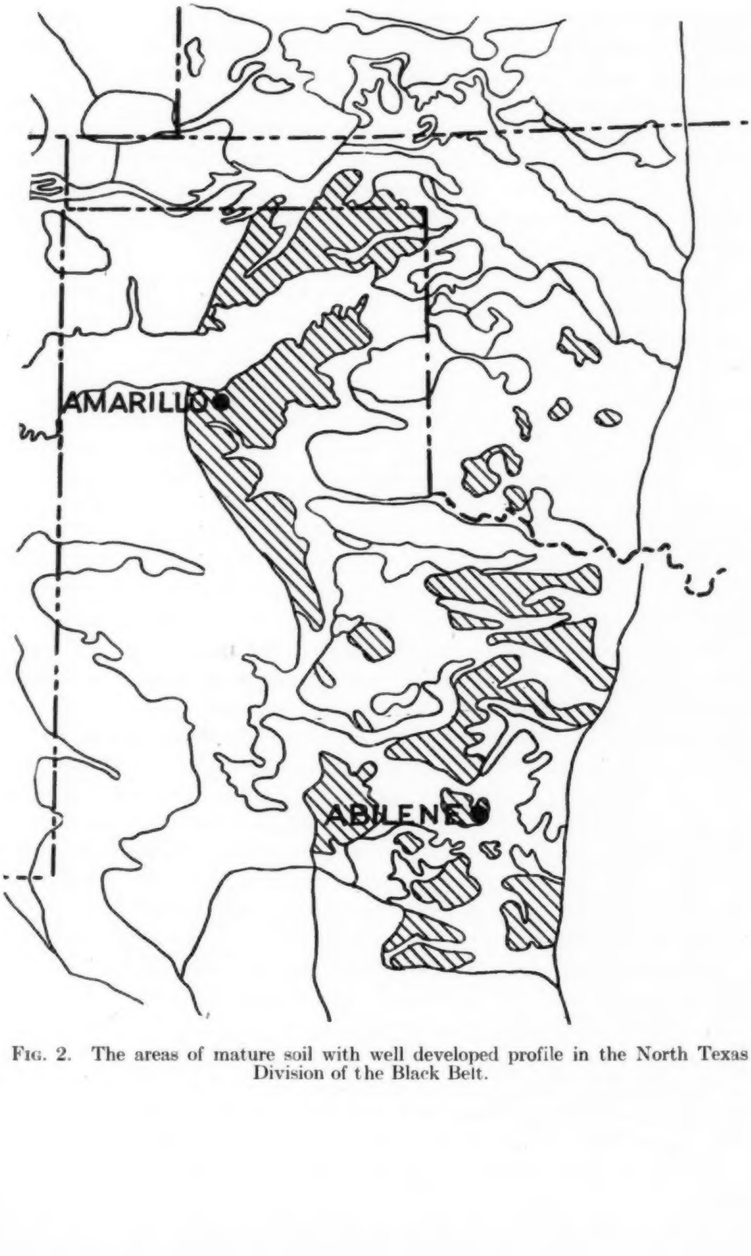


FIG. 2. The areas of mature soil with well developed profile in the North Texas Division of the Black Belt.

area has not been mapped, except in small spots here and there, so that the map given here is very much generalized and imperfect. It will be noted that a larger proportion of mature soil is found on the High Plains around Amarillo than in other parts of the area.

The development of the soil in sandy areas runs parallel with that on rough topography. A considerable area of sandy soil, and therefore of soil without the features of the normal or mature soil of the region, lies in Western Oklahoma. Profiles of the mature soil at Miami, Texas, and at Snyder, Texas are as follows:

Richfield clay loam, Miami, Texas.—

1. Dark brown granular clay loam............ 0 to 12 inches
2. Brown clay with faint reddish shade, no noticeable granulation, breaks on drying to rough columns and irregular clods.............. 12 to 30 inches
3. Reddish brown clay with lime carbonate concretions.

Amarillo loam (or sandy loam) Snyder, Texas.—

1. Dark brown sandy loam with faint reddish shade, granular .... 0 to 12 inches
2. Dark reddish brown loam, cloddy............ 12 to 26 inches
3. Reddish brown clay loam, cloddy............ 26 to 34 inches
4. Highly calcareous horizon, loose, pinkish...... 34+

The Edwards Division.—

This area covers the eastern part of the Edwards Plateau in Texas. It is a region of smooth plateaus separated by valleys varying greatly in width. The valleys may consist of narrow gorges or of broad lowland belts in which the actual stream valley is an insignificant feature. The location and distribution of the area is shown on the map Fig. 1.

The soils are all shallow and lie on limestones with the exception of insignificant belts of shales, always calcareous, and the larger area of the Llano basin where the soils overlie sandstone in part and granite in part. Throughout the whole region the soil has developed from material accumulated by the decay and disintegration of rocks similar to those on which it lies.

The soils are so shallow that the normal profile is rarely developed. It is only in especially smooth places that a normal profile is seen. One at El Dorado, Texas, is as follows:

1. Very dark brown to black clay loam.............. 0 to 2 feet
2. Reddish brown clay .... 0 to 3 feet
3. Pinkish white carbonate zone, indurated to caliche in places. It varies rapidly in depth, ranging within a zone about a foot thick...................... 3 feet +

The most common profile consists of a few inches of black to very dark brown clay loam ranging up to 12 to 16 inches in thickness, becoming sometimes reddish in the lower part overlying a cap of accumulated indurated lime carbonate lying on and adhering to the underlying limestones. The dark color of the soil seems to be due, in part, as in the Dakota area, to the calcareous parent rock. The predominant soil therefore is immature, still retaining the influence of the parent rock. This gives it a darker color than the mature soil of the North Texas Division. It is therefore a soil with Rendzinas characteristics. Even in its most mature phases, as at El Dorado. it is darker than the normal mature soil of the region. On the valley slopes there is very little soil present, most of them consisting of limestone outcrops with pockets of dark colored soil here and there, or streaks and benches of gray soil consisting essentially of disintegrated gray calcareous shale.

The soil in the Llano basin is brown and since the area is rolling, consists mainly of reddish sandy clay with the carbonate zone undeveloped except on the relatively unimportant flat areas.

The Edwards area supports an open stand of scrubby trees, mainly oak. The older, larger trees stand singly, the younger in groups, giving a park-like character to the region. No trees grow on the Dakota or Kansas areas of the Chernozem belt but Mesquite trees grow on the North Texas area from the Red River southward; they do not extend on to the High Plains portion of the belt. Oak trees do not grow on the North Texas Division. The Edwards area is utilized almost exclusively for grazing.[2]

A relatively small area surrounding the town of Fredericksburg is used for general farming and the valley of the river above and below Menard is irrigated and used for growing general farm crops. The population is very sparse and is confined mainly to the few towns of the area. San Angelo, an important town, is the metropolis of the region.

The South Texas Division.—

The location and extent of the area, extending from San Antonio to Brownsville, Texas, are shown on the map Fig. 1. It consists of two sloping plains, one extending from the foot of the Edwards Plateau, westward from San Antonio, as a southeastwardly sloping plain to a few miles beyond the Nueces River; the other starting from the top of a rather poorly defined escarpment rising from the southern boundary of the northern plain and sloping thence southeastward to

2. Dr. B. Youngblood. An Economic Study of a Typical Ranching Area on the Edwards Plateau of Texas. Texas Agr. Exp. Sta. Bul. 297.

the Gulf. A broad belt extending along the valley of the Nueces River to its southward bend and thence in the same direction to the boundary of the area marks the low part of the northern plain, the abruptly rising edge of the southern lying a few miles southeast of the river. The soils of the area vary to a considerable extent, the range in variation being expressed fairly well by the following profiles.

Five miles south of Floresville, Texas.—

1. Dull dark-brown sandy loam................	0 to 10 inches
2. Dark reddish brown heavy sandy clay that hardens and cracks on drying, somewhat calcareous; cracks irregularly on outcrops.......	10 to 14 inches
3. Pinkish gray calcareous clay................	14+ inches

Five miles south of Beeville, Texas.—

1. Dark brown sandy loam...................	0 to 10 inches
2. Reddish brown clay loam.................	10 to 24 inches
3. Pinkish gray mass of lime carbonate and clay with indurated lime carbonate crusts........	24 in. +

Thirty-eight miles south of Falfurrias, Texas.—

1. Dark brown sand and loamy sand............	0 to 12 inches
2. Grayish brown sandy clay................	12 to 40 inches
3. Caliche	40+ inches

Three miles south of Kingsville, Texas.—

1. Black clay loam.........................	0 to 12 inches
2. Gray clay calcareous.....................	12 to 48 inches
3. Light gray to nearly white clay with abundant selenite crystals	48+ inches

The soils, where mature, are not black. The heavier and less mature soils are darkest in color. In all cases where mature soil has developed from sandy clay deposits the surface soil has become a sand, the clay being washed into the subsoil. Where the soil has been well drained for a long period and has rolling topography, the subsoil becomes invariably red, the carbonate zone becomes indurated to a caliche and is often many feet in thickness. On the other extreme of drainage and stage in development the surface soil is a very dark gray clay and passes downward within less than two feet to a gray calcareous deposit of late geological age. This is the Victoria clay, as mapped by the Bureau of Soils. It occupies a large area around Corpus Christi Bay.

The escarpment, forming the abrupt rise from the low southern border of the northern plain to the higher northern border of the southern plain is made possible by the outcrop, along its top, of the caliche horizon lying beneath the Duval soils which occupy the high

northern border of the southern plain. The Houston soils along the low belt of the northern plain are immature soils in which the carbonate zone has not yet become indurated or highly concentrated. These are not true Houston soils, the latter being true Rendzinas found in thoroughly humid regions. The soils mapped as Houston in this area however, are half Rendzinas and half Chernozorus somewhat like, in that respect, the Dakota Division soils and those of the Edwards Division.[3]

The Very Dark Brown Belt.—

The location and distribution of the belt are shown on the map Fig. 1 It is confined to the Dakotas. Future work in the region west of the Black Belt and south of the Dakotas may obtain data that will warrant extending it across the Plains from north to sonth. At present it cannot be done.

The soils so far as color is concerned are sufficiently described by the name applied to the belt. They are merely less black or less dark in color than those of the Black Belt.

The carbonate horizon lies a little nearer the surface than in the Black Belt ranging approximately between the depths of 24 and 30 inches.

The topography is essentially like that of the Black Belt except in the section that contains the Missouri River Valley. A narrow belt on each side of that stream consists of recently laid alluvium and of rough land along the river bluffs, the soils in both cases being immature, that feature expressing itself in the absence of the carbonate zone.

A narrow belt along both sides of the several small rivers and creeks entering the Missouri from the west is of the same character. This incledes the narrow belt of "bad lands" along some of these streams. West of the Missouri in South Dakota the parent rock is a fine grained shale. The glacial deposits are in most cases very thin and where present consist mainly of shale material. The soil is very heavy therefore, and in such conditions the rate of soil development is very slow. Even on the ridge tops in this region the soil is often quite shallow and the carbonate zone has not developed.

Considerable areas of soils with heavy tough clay subsoils, similar to those occurring in Beadle County, South Dakota, lie in the vicinity and west of Highmore, and between Blunt and Pierre, South Dakota.

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[3] Reconnoissance Soil Survey of South Texas, Field Operations of the Bureau of Soils for 1909 and Reconnoissance Soil Survey of Southwest Texas, Field Operations of the Bureau of Soils for 1911.

In considerable areas in North Dakota, in McHenry County, especially, the soils are very sandy.

The Dark Brown Belt.—The general distribution of the belt is shown on the map Fig. 1. The soils are dark brown to dark reddish brown, less dark in color in all latitudes than the soils of the Black Belt in the same latitude.

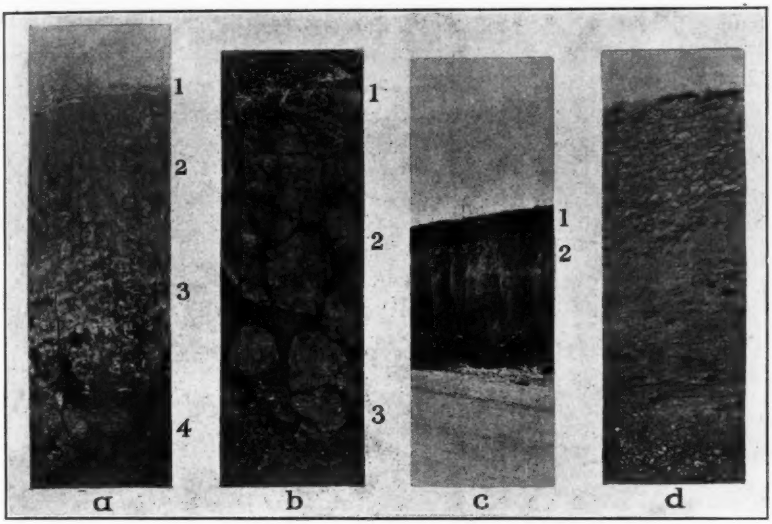
The carbonate zone lies at shallower depth than in the Black or Very Dark Brown belts to the east, ranging from 12 to 24 inches. The horizon of perfect granulation so well developed in the Kansas Division of the Black Belt, but less perfectly developed elsewhere, seems to be absent from the soils of the Dark Brown Belt*. For convenience of description and on the basis of slight variation in color and other features of less importance the whole belt may be divided into three areas; Northern, Central and Southern Divisions respectively.

The Northern Division.—The location and area are shown on the map. The mature soil of the region occurs in a series of isolated areas varying greatly in size, instead of in one unbroken or very nearly unbroken area, as in the Dakota Division of the Black Belt. This is due to a considerable area of rough land and bad lands caused by the dissection to which it has been subjected. Broad belts of such lands lie along both sides of the Yellowstone, the Little Missouri, the Cheyenne, the Missouri, the Powder and Tongue rivers and smaller belts along the smaller streams. No such belts traverse eastern North Dakota and the streams traversing the Kansas Division of the Black Belt are less effective in reducing the upland area of mature soils than in that region. All these hilly belts are covered with a shallow soil in which the normal profile has not become uniformly or generally developed. They include innumerable small areas without regularity of distribution in which the soil is mature, but these areas are not large individually or in total area.

While the typical mature soil has been described as dark brown, the belt as delineated on the map, extends far enough westward to include soils that are predominantly much less dark than those in the eastern part of the belt. This is especially true of the soils along the Milk River Valley, of those between the Missouri and the Yellowstone and of those in Eastern Wyoming and southwestern South Dakota.

The Black Hills area introduces a group of foreign soils into the area, the greater part of them consisting of light colored timber soils

*This statement is true in general. The horizon seems to be imperfectly developed along the eastern border of the belt in Kansas, as the boundaries are now placed. It may be found advisable in the future to place the western boundary of the Black Belt farther west than at present, and possibly along the western boundary of the granular horizon.



a. Profile at Glasgow, Montana. Horizon 1 is structureless and thin; 2 is columnar; 3, the carbonate zone, and 4, the parent material, calcareous but less so than horizon 3. Dark Brown Belt.

b. Section of soil removed from a roadside excavation and photographed in a horizontal position. Horizon 1, very thin, is structureless; 2 is columnar, rather imperfectly so and 3, is the carbonate zone. Dark Brown Belt in southwestern Kansas.

c. Deep road cut near Akron, Colorado. Dark Brown Belt. Shows the carbonate zone indurated to a caliche.

d. Railroad cut ten miles west of Santa Rosa, New Mexico, showing caliche immediately beneath the surface. The fragments are those of caliche and not of limestone. Brown Belt.

similar to those in northern Minnesota and Wisconsin, but this central area is surrounded by a more or less continuous but narrow band of Black Earth and this in turn by a still less continuous belt of Very Dark Brown Soils..

The typical medium textured soil of the area has a profile about as follows:

Profile of Mature soil, Dickinson, North Dakota.—

1. Brown structureless light loam.............	0 to 2½	inches
2. Dark brown somewhat granular loam........	2½ to 9	inches
3. Brown loam	9 to 14	inches
4. Loose structureless, carbonate zone..........	14+	inches

Soils of this general character prevail southward into northern south Dakota. South of that in South Dakota, Nebraska and southeastern Wyoming, the soil is heavy, though the profile is usually well developed. In northeastern Wyoming and southeastern Montana the soil is about as dark in color as at Dickinson, but the surface horizon is somewhat lighter in texture. The individual areas are narrow, separated by belts of rough land with immature soils.

Along the Milk River, around Jordan and Miles City, Montana, there are many " Slick Spots " or " Buffalo Wallows " or "Blowouts " consisting of small areas ranging up to 30 feet in diameter, bare of vegetation, depressed usually about five inches below the surrounding area, the surface of the basin consisting of a heavy tough clay. The clay horizon ranges up to a foot in thickness, below which lies friable clay or lighter textured material. The clay bed and material below usually contain salt segregations and gypsum crystals. These spots may be thickly or thinly sown over an area. They occur mainly on level or in slightly depressed situations. They seem to be essentially like the soil with heavy subsoil described from Beadle County, North Dakota and elsewhere, in which the clay horizon is locally developed in spots and from which the lighter soil above has been blown away. They may be seen in all stages of development from the Beadle County type to the fully developed " slick spot."

A western outlier of this division of the Great Plains soils covers the area of the Judith Basin in Fergus county, Montana. It consists of a lowland, roughly circular in shape, surrounded discontinuously by mountains, none of them very high but all high enough to promote the formation of summer thunder showers. The influence of the mountains extends over the basin, over the low belts between the links of the encircling chain of mountains and a narrow belt surrounding the mountains on the plains outside. The basin has been filled to a

depth of many feet by a series of alluvial fans spread out toward the center from the surrounding mountains. Similar fans are built outward on the plains from the outer slopes of the mountains. The gravel of which the fans are built contains a significant to large percentage of limestone pebbles. The soils developed from these deposits are somewhat like those of the Dakota and Edwards Divisions of the Black Earth belt to the extent that they are darker in color than they would be were the parent material less calcareous or were the soils more advanced in their stage of development.

The soils are universally shallow, it being often less than two feet to the unchanged parent gravel beds. A section measured in an excavation on the Experiment Farm at Moccasin, Montana is as follows:

1. Brown, loose structureless heavy loam (Plate II, b and c)	0 to 3 inches
2. Dark brown, somewhat granular clay loam	3 to 10 inches
3. Yellow brown clay loam	10 to 20 inches
4. Carbonate horizon	20+

As the mountains are approached in any direction from a point in the basin the soils become darker, first very dark brown and finally black, then changing rapidly as the timber covered slopes of the mountains are reached to light colored typical woodland soils. The same series of belts may be crossed in approaching the mountains from the plains outside the basin. The belts are usually narrow however, and are not developed where the topography is not smooth.

Narrow belts of similar character lie along the Rocky Mountain Front. The eastern part of each belt has dark brown soils. Westward the soils become darker and in places there are areas of narrow strips of true Black Earth lying directly under the mountain front. The soil just east of Glacier Park Station on the Great Northern Railway seems to be of such a character. South of this the belt in which are situated the towns of Valier, Conrad, Dupuyer, Chouteau, Fairfield and Augusta, Montana, is covered with soils of dark brown color; the color running somewhat lighter than at Dickinson, North Dakota, and darker than on the upland between the Yellowstone and the Missouri. Similar soils are known to lie along the mountain front east of the Crazy Mountains, and the Red Lodge Country, along the east foot of the Big Horn Mountains, and the Rocky Mountain Front between Denver and Colorado Springs. They seem to be present locally between Raton and Las Vegas, New Mexico.

The part of the Northern Division lying in North Dakota, except the southwest corner, and the adjacent part of Montana, especially the

region around Wibaux has been developed into a wheat growing region of no importance. The same is true of a belt along the Canadian border from the eastern boundary of the state westward into Blaine county, Montana. In South Dakota most of the area is utilized for grazing.

The Central Division.

The location and extent of this area are shown on the map (Fig. 1). The area is smoother than that of the Northern Division. It is crossed by the North Platte, the South Platte and the Arkansas. The North Platte is the only stream along which any considerable belt of rough or bad land topography has been developed. In most of the area therefore, the soils are approximately mature except for the areas of sands of which there is a much larger area than in the Northern Division. Sands have a very restricted distribution in the latter area.

The soils, as a whole, are somewhat lighter in color than in the typical area of the Northern Division, the carbonate zone ranges around 16 to 20 inches in depth and the granular horizon, as further north, seems to be lacking.

The character of the soil of intermediate texture is shown by the following profiles.

Profile at Dalton, Nebraska.—

1. Medium dark brown loam..................	0 to 4 inches
2. Brown loam, imperfectly cloddy.............	5 to 14 inches
3. Loose calcareous horizon	14+ inches

Profile at Akron Experiment Station, Akron, Colo.—

1. Brown silty loam, deflocculated, showing a pronounced horizontal or layered arrangement in natural position	0 to 8 inches
2. Dark brown, columnar clay or clay loam, compact rather hard when dry, columns half an inch to an inch in diameter, each having well defined horizontal breakage...............	8 to 16 inches
3. Gray loose, highly calcareous material........	15+ inches

Profile nineteen miles north of Elkhart, Kansas.

1. Loose brown loam, structureless..............	0 to 4 inches
2. Brown clay loam, faintly granular, dark shade..	4 to 12 inches
3. Yellowish brown clay loam..................	12 to 15 inches
4. Yellowish brown clay loam, calcareous........	15+ inches

Profile three miles west of Two Buttes, Colorado.—

1. Brown clay loam, dark shade, somewhat granular.	0 to 8 inches
2. Brown clay loam, cloddy....................	8 to 11 inches
3. Calcareous horizon	11+ inches

Not including the sand hills, the mature soils of the area do not vary widely. Areas of sand occur on the plains west of Alliance, Nebraska, in the region of Wray, Colorado, east of Sugar City, Colorado, and along the Arkansas.

The part of this division lying between the two Platte Rivers in Nebraska, has been utilized for agriculture more completely than any other part. though a great deal of northeastern Colorado and northwestern Kansas is about equally as fully used for crop growing, mainly wheat. The western part of the area is not used extensively for crop growing anywhere. This statement does not apply to the irrigated regions in the valleys of the two Platte Rivers in Wyoming, Nebraska and Colorado.

The profile at Akron, Colorado, represents one of the two profiles that prevail throughout the area of the Central Division and that at Dalton, Nebraska the other. The former shows the extreme development of this profile. Its characteristic features are the light colored, loose defloculated surface horizon and the darker colored, more compact subsurface horizon with well defined columnar breakage, below which lies the carbonate horizon with or without an intermediate lighter colored horizon. The extreme development of this profile at Akron is shown in the 8 inch thickness of the surface horizon and in the extreme development of the columnar breakage of the subsurface horizon on outcrops. Throughout the greater part of the area of the division the thickness of the surface horizon will range around one to two inches. The columnar breakage in the subsurface horizon is less well developed as a rule, the columns are larger, the shape less uniform, the surface less smooth and the horizontal breakage much less perfect.

In the Dalton profile the differentiation into the gray horizon and the columnar subsurface horizon is not strongly developed. There is some imperfect development of the latter but the former is not noticeable, while the total thickness of the two (or three) horizons above the carbonate horizon is greater than in the other types.

It seems that the Dalton type of profile is more prevalent in the northern and eastern, especially the latter, parts of the area while the Akron type is prevalent in the western part but not usually in extreme form. The latter is prevalent over the former. Both types of profiles are as characteristic of the Northern Division as of the Central.

The Southern Division.—

The location and area are shown on the map (Fig 1). The lines between the Black Belt and the Dark Brown Belt and between the latter and the Brown Belt as they have been located on the map are based on a smaller amount of actual information than is true of most of the other boundary lines. While it is true that they are all based on incomplete information and are liable to more or less change in the future, it sems probable that the boundary lines in western Texas and in New Mexico will be subjected to greater changes than elsewhere. Both the eastern and western boundaries of the Dark Brown Belt must be regarded therefore as even less definitely established on the ground than are the others.

The characteristics of the soil in the western part of the belt as now defined are shown by the profile measured at Dalhart, Texas, and those on the eastern side by the profile at Big Springs, Texas.

The soil profile at Dalhart, Texas, a profile that may be considered representative of the northern portion of the area is as follows:

Profile one mile southwest of Dalhart, Texas.—

1. Brown structureless loam.................. 0 to 1½ inches
2. Dark brown heavy loam, somewhat granular.. 1½ to 7 inches
3. Pinkish brown loam..........................7 to 15 inches
4. Pinkish yellow highly calcareous clay loam, loose 15+ inches

Profile seven miles south of Big Springs, Texas.

1. Dark brown loam........................ 0 to 5 inches
2. Dark reddish brown heavy loam............ 5 to 18 inches
3. Light reddish brown loam, with yellowish shade 18 to 34 inches
4. Pale pinkish loose calcareous horizon with hard calcareous concretions .... 34 inches +

The profile at Big Springs shows a soil a good deal darker in color than that at Dalhart. The zone of carbonate accumulation is deeper and the subsurface zone is less columnar in its breakage on outcrops. The latter characteristic is more typical of the soils of the Dark Brown Belt than is the profile at Big Springs, while that at the latter place is more like the profile in the Chernozem than is that at Dalhart. Further investigation may show that the western boundary of the Chernozem belt (The Black Belt) should run west of Big Springs.

The southern part of the area, except the extreme southern part, is occupied by a westward extension of the Edwards Plateau and could be separated from the rest as a distinct division as was done in the case of the Black Earth belt. This has not been done in this belt because of the lack of definite information regarding the soils. It is known that

the soils are shallow and underlaid by a pinkish carbonate zone or by limestone, but whether the limestone is capped by a thin caliche, or not, is not known. The color of the soil is not known, though such information as is available indicates that it is lighter in color than the soils of the Black Earth Belt.

In the western part of the area in Texas, however, there are many square miles of sandy soils. In some cases the sands are several feet thick, in others thin, the underlying red clay or sandy clay appears at three feet or less. A belt of sandy soils lies between Seminole and Lamesa, Texas, and extends southward many miles. Another lies between Lubbock and Clovia, and another between Clayton, New Mexico and Dalhart, Texas. Considerable areas lie in the Oklahoma panhandle.

Grazing is the predominant industry, almost the exclusive one on the western area. On the eastern area considerable crop growing has developed locally, especially in the vicinity of La Mesa, Big Springs and along the eastern border. Cotton and sorghums are the predominant crops.

The Brown Belt.—

This is a discontinuous belt, broken up into several separate parts, the location and extent of each being shown on the map (Fig. 1.) The soils of this belt are the lightest in color of all the Great Plains soils and the carbonate zone beneath them is shallowest. The color of the soil is brown rather than distinctly dark brown, but, as compared with the lighter colored soils of the deserts, it may be placed, with sufficient justification, with the dark colored soils. Like the other Great Plains soils it has developed under a grass cover but one of somewhat less dense growth than on the other belts. These soils, where the belt in which they occur is not bounded on its western side by the mountains or by the "Mountain foot" belt of darker colored soils, change westward by imperceptible gradations into the still lighter colored soils of the deserts.

A typical profile of the soil in the northern area, sampled a few miles south of Chester, Montana, is as follows:

Profile ten miles south of Chester, Montana.—

1. Light brown loose defloculated loam...........	0 to 2 inches
2. Brown clay loam.........................	2 to 12 inches
3. Grayish highly calcareous clay loam..........	12+ inches

A number of samples collected from various localities in this area show the color and depth to the carbonate zone to be quite uniform.

"Slick Spots" are of common occurrence in many parts of this area, the most abundant seeming to occur from the Milk River, a few miles west of Havre, southward to the Marias River. Another area lies in the flat land area in the vicinity of Shelby, Montana, and a string of them extends down the Milk River valley from Havre to Malta, though these lie mainly within the belt of Dark Brown soils. Areas of soils with high content of alkali salts also occur in the vicinity of Shelby.

This area is continued by a very narrow belt running southward by way of Sheridan, Wyoming between the Big Horn Mountains on the one hand and the elevated plateaus east of Sheridan on the other. South of Sheridan it widens to include most of eastern Wyoming. The soil in the eastern part of the area is somewhat more sandy and apparently also less naturally developed than in the western part, excepting on areas in the vicinity of Caspar. The soils are brown and the carbonate horizon lies about 12 to 15 inches beneath the surface.

The Colorado area varies considerably in the character of its soils. In the northern part the soils are very much like those in the northern area, becoming a little reddish just above the carbonate horizon. A profile measured near Wild Horse, Colorado is as follows:

Profile three miles east of Wild Horse, Colorado.

1. Light brown loam loosely defloculated........	0 to 6 inches
2. Brown loam, darkish shade, columnar breakage on drying	7 to 17 inches
3. Gray calcareous zone......................	17+ inches

In the southern part of the area the grass cover is less dense than anywhere else east of the mountains and the vegetation assumes an appearance approximating that of the desert vegetation. The soils are still lighter in color except where dominated by the color of the parent rock, a brown shale, and the salt content is sufficient to cause the development of a rather well defined alkali profile. A profile measured at Avondale, Colorado is as follows:

Profile three miles northeast of Avondale, Colorado.—

1. Light brown loose structureless sandy loam....	0 to 3 inches
2. Brown sandy clay loam columnar breakage....	3 to 13 inches
3. Gray loose calcareous material...............	13+ inches

The soils of the Brown Belt between Raton and Las Vegas, New Mexico seem to be darker in color than those in the Colorado part of the belt. Our knowledge of the characteristics of the New Mexico portion of the belt is very defective. It has been traversed but once,

this traverse running from Raton by way of Springer and Wagon Mound to Las Vegas. The eastern part of the area is practically unknown.

The route from Raton to Las Vegas lies but a short distance east of the mountains and the soil is probably darker than it is further east. On account of this probability no attempt has been made to give this area any special designation on the map. That part of the Brown Belt lying south of Las Vegas, extending at least as far south as the south line of New Mexico has a well defined *caliche* (Plate II,d) or indurated carbonate zone lying at a very shallow depth. In a large part of the area it is barely covered with soil and in others it lies on the surface, there being practically no soil except what lies in depressions in the surface of the caliche. The soil in many places seems to be little else than a product of the decomposition of the upper part of the caliche. In other places such soil as is present consists of accumulations of blown sand. The sand is especially abundant on the bench on the east side of the Pecos river south of Ft. Sumner and on the western escarpment of the High Plains lying approximately half way between the Texas line and the Pecos river. Between the top of the escarpment and the western line of the Dark Brown Belt the soil is not sandy as a rule, but it is shallow.

The Pecos River from a few miles south of Ft. Sumner New Mexico, flows southward through a region that becomes more and more desert-like in its features southward until in the Tova basin around Pecos, Texas, the desert characteristics dominate every other. It is possible that future study may obtain data that will warrant the extension south of Roswell and thence eastward between the Teyah desert on the west and the Dark Brown belt on the east. Such a belt if it exists, may include the western and the Edwards Plateau, from Sanderson westward.

Annals of the Association of American Geographers
Volume XIII, pp. 67-80

THE CLIMATE OF THE GREAT PLAINS AS A FACTOR IN THEIR UTILIZATION

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CONTENTS

Introduction. A number of geographic factors, principally climate, topography, and soil fertility, operating either separately or in varied combinations, influence agricultural conditions. Of these, climate is the most fundamental, unalterable and important, not only in influencing the distribution of particular crops, but also in determining the suitability of land for agricultural purposes. The land surface of the earth may be classified broadly as potentially agricultural and non-agricultural. The potentially agricultural land may be designated as productive and non-productive, and the former subdivided according to suitability for crops, pastures, or forest, based largely on climatic conditions.

Agriculturally, the United States is one of the most favored countries of the world. Large areas of its land surface are potentially agricultural, with climatic conditions favorable for crop growth, particularly in the eastern half of the country. In the west, however, much of the land is semi-productive, as the climatic elements do not occur in the best combination to favor intensive cultivation. Precipitation is usually the limiting factor. The most important single area to be classed as semi-productive is the region of the Great Plains lying just east of the Rocky Mountains.

Moisture Limitations.—*Annual Precipitation.*—By selecting crops with the proper thermal requirements, each staple crop produced in the United States could be grown with profit in some section of the Great Plains, so far as temperature is concerned. The agricultural utilization of the region, however, is limited by moisture conditions, especially

in the central and southern portions. There is a gradual decrease in the average annual precipitation from more or less humid conditions in the east, to semi-arid, or even arid, in the west.

Figure 1 shows that the average annual precipitation ranges from 20 inches in extreme eastern North Dakota, to 25 inches in south- central South Dakota, central Kansas, and west-central Texas and Oklahoma, to less than 15 inches in much of Montana, eastern Wyoming, eastern Colorado, and the Brazos Valley in western Texas and eastern New Mexico. The minimum precipitation in the area is about 6 inches, in the Bighorn Valley of Wyoming. In the vicinity of Hyatville in this valley the average precipitation for a 12-year record is only 4.5 inches, and in 1921 only 3 inches fell.

The chart shows that there is a rather uniform diminution of precipitation from the eastern to the western portions of the Plains, except in Montana. The central and eastern portions of this State have a more diversified topography, thus a greater variation in rainfall than other portions of the Great Plains area. Where the surface is more or less uniform, as in the Yellowstone, Missouri, and Milk River valleys, trending in a general east-west direction, we find correspondingly small variations in precipitation, the amounts being nearly the same in all of these valleys, ranging mostly between 12 and 14 inches. There are some localities in the vicinity of Chester, Mont., where the annual precipitation is only slightly more than 10 inches. Southeast of these, in the Little and Big Belt Mountains, the amounts exceed 20 inches: a record covering 7 years shows an annual average amount of 30.24 inches near Garneille, in a pass between the Little Belt and Big Snowy Mountains, the greatest amount, except for some very short records, shown for any station in Montana east of the Rockies.

The minimum amount of annual precipitation necessary for successful farming by ordinary methods is usually considered to be between 15 and 20 inches. With an annual rainfall of less than 15 inches, other conditions must be very favorable to ensure successful crop production.

Much of Australia is similar to the Great Plains area in moisture conditions. In considerable portions of the winter wheat belt of Australia, dry-farming methods of fallowing and tilth are practiced extensively, and only one-third of the area is under wheat at a time. The determination of dry-farming areas there, depends principally upon the rate of evaporation. In some regions areas receiving less than 18 inches of rainfall are classed as dry, while others are so

classed when the rainfall is nearly 25 inches. It is considered that every 3 inches of free water surface evaporation requires 1 inch of rain in addition as an offset.

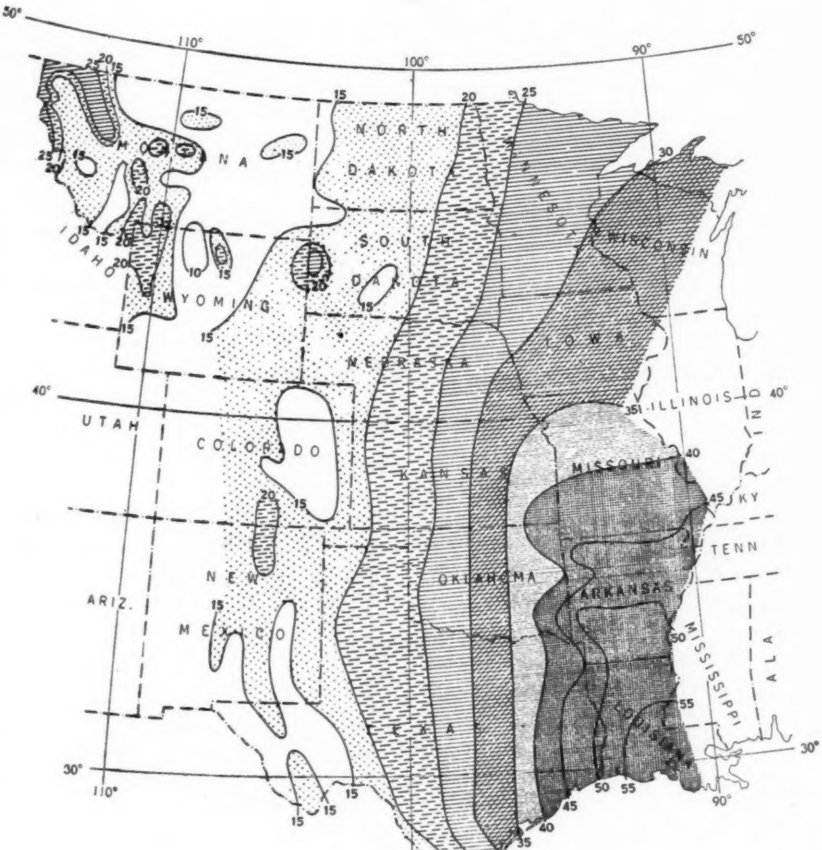

FIG. 1. Average annual precipitation over the Great Plains and adjoining sections.

In the Great Plains the agricultural significance of the rainfall depends principally on its seasonal distribution, the variations in amount from year to year, and the rate of evaporation. All of these modifying factors operate more favorably in the northern half than in the southern. The result is, that while rainfall is scantier in the north, conditions there are climatically more favorable for crop growth than elsewhere in the region.

Seasonal Distribution.—In the Great Plains, it is the rainfall of the crop growing season with which the farmer is mostly concerned. While the moisture stored in the soil at the beginning of spring is important, the amount is generally small, owing to the scanty winter precipitation, and therefore crops must depend largely on spring and summer rains. While the annual rainfall is light, the seasonal distribution is very favorable for the fullest utilization of the moisture received, particularly in the northern portion of the region. Winter precipitation is very light, less than ten percent of the annual amount occurring in most of the central and northern portions during the three months from December to February. With the advance of spring the amount increases rapidly. In Montana and the Dakotas, May and June are usually the months of greatest rainfall, while elsewhere, May, June, and July are about equal, except in western Texas and eastern New Mexico, where July leads.

Figure 2 shows the average warm season rainfall, April to September. It indicates that the amounts during this period of the year vary from 18 inches in northwestern Minnesota, extreme southeastern North Dakota and eastern South Dakota to less than 9 inches in parts of north-central Montana, and to less than 6 inches in north-central Wyoming. Farther south, the amounts range from 24 inches in the eastern portions of the Plains States to about 12 inches near the eastern foothills of the Rockies.

In the eastern half of North Dakota and much of northern South Dakota, more than 80 per cent of the annual precipitation occurs during the six warmer months of the year, April to September, and over practically all other parts of the area between 70 and 80 per cent occur during that period. In the Dakotas approximately half of the average annual amount is received during the three summer months.

Rainfall Variability.—When the average amount of precipitation borders on the minimum required for crop production, as is the case in much of the Great Plains, the variation from year to year, becomes of very great importance. In general, there is less than the normal amount of rainfall in more than half the years. In the northern portion of the Plains, the annual variations are comparatively small,

which is favorable to permanent agriculture, but in the south they are large, and less favorable, and rainfall is more frequently of a torrential character.

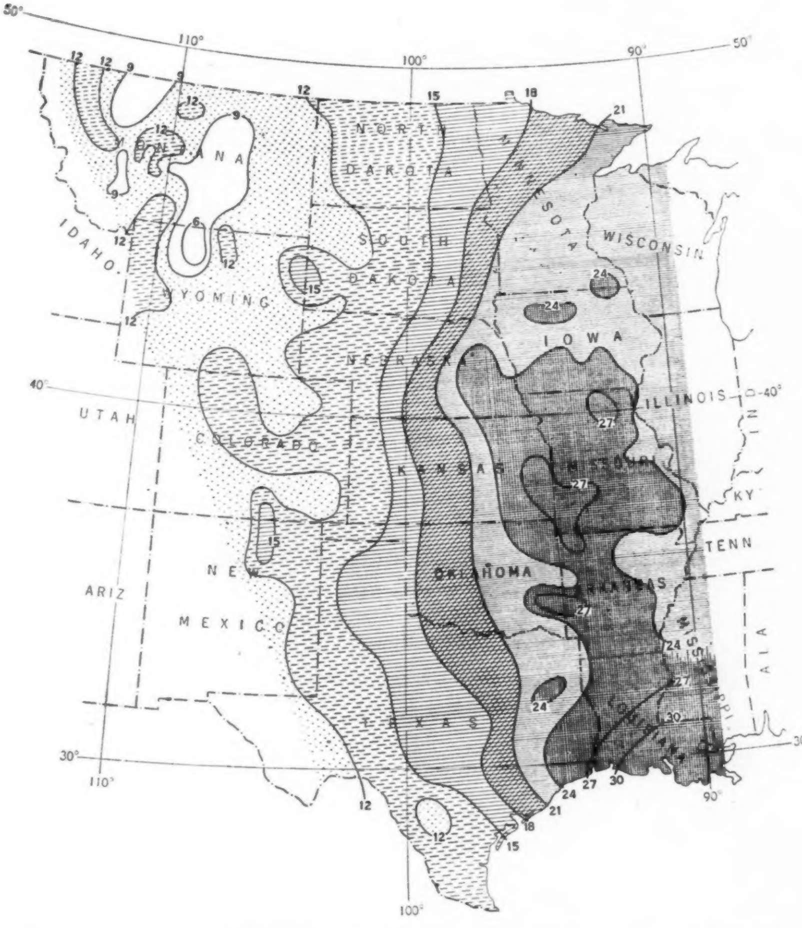

FIG. 2. Average warm season precipitation (April to September, inclusive) over the Great Plains and adjoining sections.

There is a well recognized tendency for precipitation in the Plains region to show several successive years of comparatively generous rainfall, followed in turn, by several years with deficient moisture, and this renders farming by ordinary methods precarious in many of the drier western portions of the section. Abundant crops in years of ample moisture encourage the western extension of the cultivated area, but the records show that these are only temporary conditions, and are likely to be followed by years of drought when the rainfall is entirely insufficient to mature crops. Disaster is sure to follow unwise agricultural adventures of this kind.

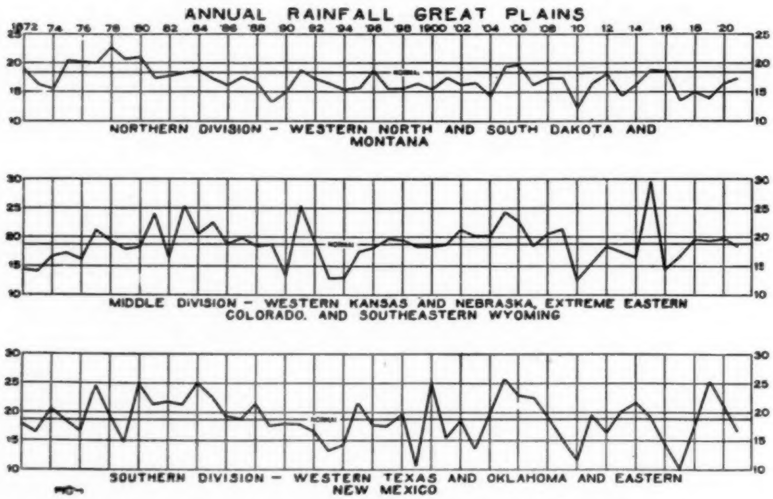

FIG. 3. Graphs showing variations in annual rainfall for a period of 50 years for the northern, central, and southern sections of the Great Plains region, each based on 12 to 20 rainfall records well distributed over the sections.

Figure 3 shows the variation in annual rainfall for a period of 50 years for the northern, central, and southern sections of the region, each based on 12 to 20 long-record stations well distributed throughout the area. These data show tendencies for comparatively humid and dry years to occur in groups, but without dependable regularity. They offer no evidence that rainfall is either permanently increasing or decreasing in any section. The fact is emphasized, however, that, while the average rainfall is somewhat lighter in the northern portions it is more dependable and therefore more favorable for stable agricultural enterprises. It will be noted that a three year period from 1917

to 1919 in the northern Plains had the greatest accumulated deficiency in rainfall shown for the entire 50 years of record.

Evaporation.—The rate of evaporation of moisture from the soil depends principally on the temperature, relative humidity, wind movement, soil composition, and the amount of moisture present. The increase in the rate from north to south over the Great Plains is pronounced. The warm season pan evaporation in the northern portion is slightly more than 30 inches as compared with about 60 inches in the south. The agricultural significance of these data, stated in terms of actual equivalent rainfall for the different areas, can be determined only approximately, since the variation in soil texture, the seasonal distribution and more torrential character of precipitation in the south, as compared with the north, introduce modifying factors not susceptible of direct quantitative evaluation.

It is probable, however, that the difference of 30 inches in evaporation between the north and the south is equivalent to about 10 inches of annual rainfall. The 20-inch annual isohyetal line conforms roughly to the 100th meridian of longitude, although its northern end extends farther east. In the Dakotas, the region through which it passes is largely devoted to crops, but in Texas, the land is mostly given over to grazing. In fact, one of the most important wheat producing sections of the country is found in eastern North Dakota, with an annual precipitation of about 20 inches.

Snow and Hail.—The average annual amount of snowfall ranges from about 30 inches in the Dakotas to 10 inches in extreme northern Oklahoma, but drops to 1 inch in southwestern Texas. Owing to low temperatures, the snow in the north is usually very dry, however, with a low water content, and frequently is drifted badly by high winds. The average annual number of days with the ground snow-covered drops from 120 in the extreme north to about 10 days in central Oklahoma. Hail is comparatively frequent in much of the region, particularly in the west-central portion where about 3 hailstorms occur usually at each point of observation during the growing season. In the extreme north and extreme south hail occurs, as a rule, on only one or two days, and is seldom experienced in the extreme lower Rio Grande Valley. These data, however, include all occurrences of hail, regardless of its severity, while it frequently occurs with little or no damage resulting.

TEMPERATURE.—Temperature conditions vary greatly in the Great Plains States. The physical aspects of the region are such as to favor normal latitudinal variations, typical of interior continental climates. Important local variations in temperature, due to topographic influ-

ences, are in evidence, but these are not the dominating temperature controls. Owing to its location in the center of the continent, far removed from marine influence, and the absence of transverse mountain barriers, the region is subject to pronounced changes in temperature, particularly in winter. The range from north to south is large. In general the winters in the northern half are frequently severe, sometimes with long periods of abnormally cold weather and at other times with rapid changes from day to day.

Figure 4 shows that the mean winter temperature in the extreme northeastern portion of the region is slightly above zero, with a rather uniform increase southward and southwestward. The increase over the Dakotas averages one degree for about 33 miles, but farther south it is somewhat less rapid. The range from the northern to the southern portion of the region is about 50°. Very low temperatures sometimes occur in the central and northern portions of the region. At some time during an average winter the temperature may be expected to fall as low as 40° below zero in northwestern North Dakota, 25° below in western South Dakota, and 10° below in southwestern Kansas, but no official sub-zero records have been made south of the 31st parallel in southwestern Texas.

As a further indication of winter temperature conditions in this region, it may be said that freezing weather, or colder, should be expected on slightly more than half the days in the year in eastern Montana and most of North Dakota; on more than 150 days in west-central Nebraska, 125 days in southwestern Kansas, and 40 days in west-central Texas, but freezing occurs on less than 10 days in the year in the extreme lower Rio Grande Valley. Freezing temperature has occurred in every month in the year in part of North Dakota, and zero, or lower, usually occurs on 50 to 60 days in the extreme northern portion of the Plains region.

While severe winter weather may be expected in the Great Plains, with cold, northerly winds reaching well into western Texas, much of the winter season is dry and bracing, and not uncomfortable for outdoor operations. Along the foothills of the Rockies, the cold is often markedly modified by the familiar warm, "Chinook" winds, and the western border of the region in winter is usually warmer, despite its greater elevation, than the sections farther east. In summer, the higher temperatures occur in the east. Chinook winds are of greater frequency in the more northern portions of the Plains area just east of the Mountains. They are of irregular occurrence and vary greatly in effect. They may begin when the weather is very cold, or with moderate temperature, and may be widespread or very

local. At times they cause a rise in temperature of 50° or more within half an hour and again the rise may be only 5° within an hour.

With the advent of spring, the warming-up is rapid, and much more so in the northern portion than in the southern, due largely to the more rapidly increasing length of days in the north. During

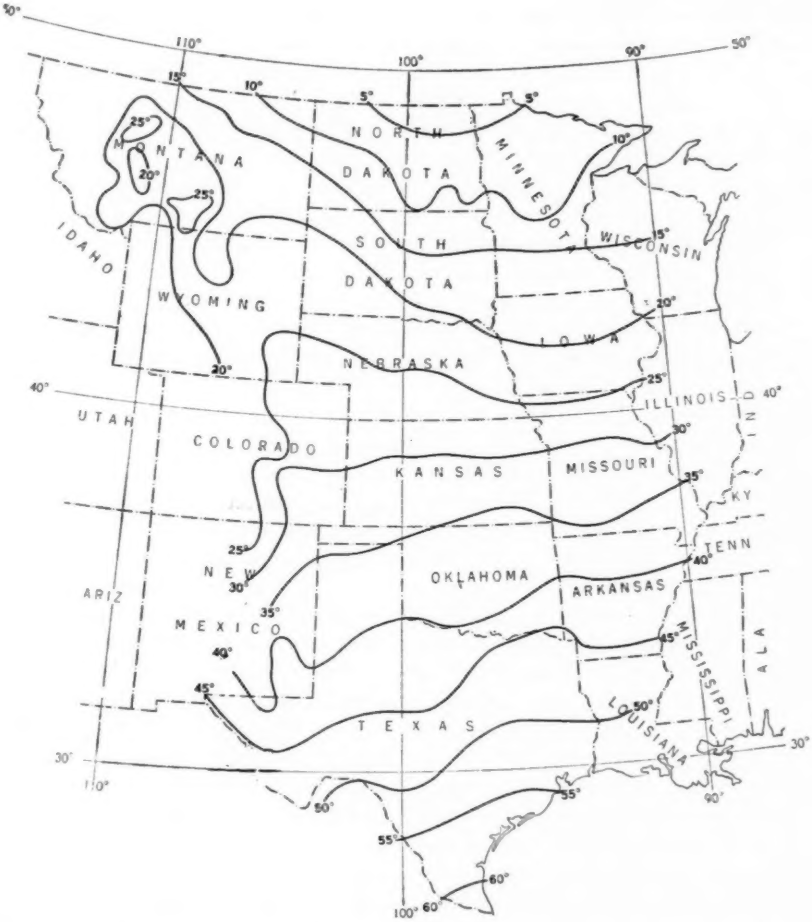

FIG. 4. Average winter temperature (December-February) over the Great Plains and adjoining sections.

March and April, the successive days become longer (sunrise to sunset) at an average rate of about three and one-third minutes in central North Dakota, and about half that number in west-central Texas. During this period, the increase in the daily normal temperature is at the rate of about 1° for each 6 minutes of increase in the day's length throughout the region.

Summer Temperatures.—Figure 5 shows that the summer temperatures in the Great Plains are much more uniform than those of winter. The average summer temperature ranges from about 65° in the extreme north to more than 80° in the south. The daily temperature range is large in summer, especially in the north, the average over much of the region being about 30° compared with 20° to 25° in the Mississippi Valley and 12° to 15° along the west Gulf coast. Periods of high temperature are comparatively frequent and are likely to accompany droughty conditions, while "hot winds," characteristic of this region, sometimes prove disastrous to vegetation. From western South Dakota and northeastern Nebraska northward to the Canadian border there is a noticeable absence of the usual decrease in temperature with increase in latitude, due largely to the lower elevation in the north.

Frost and the Growing Season.—The northward advance in spring of the average frost-free date line requires nearly three months, starting from the lower Rio Grande Valley about the first of March and reaching the northeastern part of Montana by the latter part of May. The advance is approximately at an average rate of 20 miles a day from west-central Texas northward. In general, the recession in fall is a counterpart of the spring advance as to rate and time required. The average date of the first killing frost in fall in the extreme northwestern portion is about September 10, and nearly three months later the frost line has receded to the southern border of the region.

Figure 6 shows that in the extreme northern portion of the region the average length of the frost-free season (from the average date of last killing frost in spring to the first in fall), ranges from 100 to 120 days. This increases to 160 days in east-central Nebraska and central-western Kansas, and to 200 days in northern Oklahoma and northwestern Texas. In southern Texas more than 260 days of the year, on the average, are free from frost.

The spring advance and fall recession of the average frost date line are comparatively uniform, the isochrones maintaining in general an east-west direction, but inclined from southwest to northwest. The more important sections that are favored by earlier springs and later falls and, consequently, longer growing seasons than normal for the

latitude, are the Pecos River Valley in southwestern Texas and eastern New Mexico, the Red River Valley in northern Texas and southwestern Oklahoma, the Arkansas Valley in southeastern and the upper South Platte Valley in northeastern Colorado, the upper Missouri Valley through the Dakotas and Montana, the lower elevations of

Fig. 5. Average summer temperature (June-August) over the Great Plains and adjoining sections.

the eastern Black Hills in South Dakota, and the Yellowstone and Bighorn Valleys of Montana and Wyoming. Sections where spring arrives comparatively late and fall early, and where the growing seasons are relatively short, are found on the highlands of western Texas and eastern New Mexico, in northwestern Nebraska, and from eastern Wyoming north-northeastward to southwestern North Dakota.

Climatic Limitations to Agriculture.—In a general way, from the viewpoint of temperature, crops may be divided into two classes, cool climate crops and warm climate crops. Among the former may be included potatoes, wheat, oats, buckwheat, sugarbeets, flax, and most grasses; among the latter, cotton, corn, rice, sugarcane and peanuts. Thus, by suiting a given crop to favorable temperature environment, a wide climatic range in agricultural activity may be obtained. Owing to this fact, the temperature of the Great Plains is not a dominating factor in limiting their agricultural utilization, yet, even with adequate moisture and fertile soil, the rather well-defined latitudinal boundaries of the more eastern agricultural provinces would not be maintained in all cases. For example, the northern half of the cotton belt could not extend much farther west than at present because of the comparatively low summer temperatures and short growing season in northwest Texas and extreme eastern New Mexico. Cotton requires a mean summer temperature of at least 78° and a 200-day growing season for profitable production. At the same time, this section would fall thermally within the principal corn and wheat region which would extend westward to the foothills of the Rocky Mountains.

Farther north, in northwestern Oklahoma, the western portions of Kansas and Nebraska, and eastern Colorado, temperature conditions are favorable for more or less intensive cultivation of both corn and winter wheat, although it would be rather too cool for the growth of corn commercially in northwestern Nebraska and southeastern Wyoming. So far as temperature is concerned, the extension of the principal spring wheat belt through the western portions of the Dakotas into eastern Montana and northeastern Wyoming is favored, as well as the production of other cool climate crops. Winter temperatures ranging from 20° to 40° are favorable for winter wheat. Consequently the somewhat warmer winters in the interior of Montana would bring that section more into the winter wheat belt. Sugarbeets are grown most profitably at a mean summer temperature ranging from 68° to 72°. Temperature conditions favor this crop in much of South Dakota, northern and western Nebraska, and in the extreme western portion of the Plains region from Colorado southward, as well as in

the Yellowstone Valley of Montana. With adequate rainfall, most grasses would thrive throughout the region.

It has been shown that the seasonal distribution of precipitation in the Great Plains region is favorable for vegetative utilization of a large proportion of the amount received. At the same time the avail-

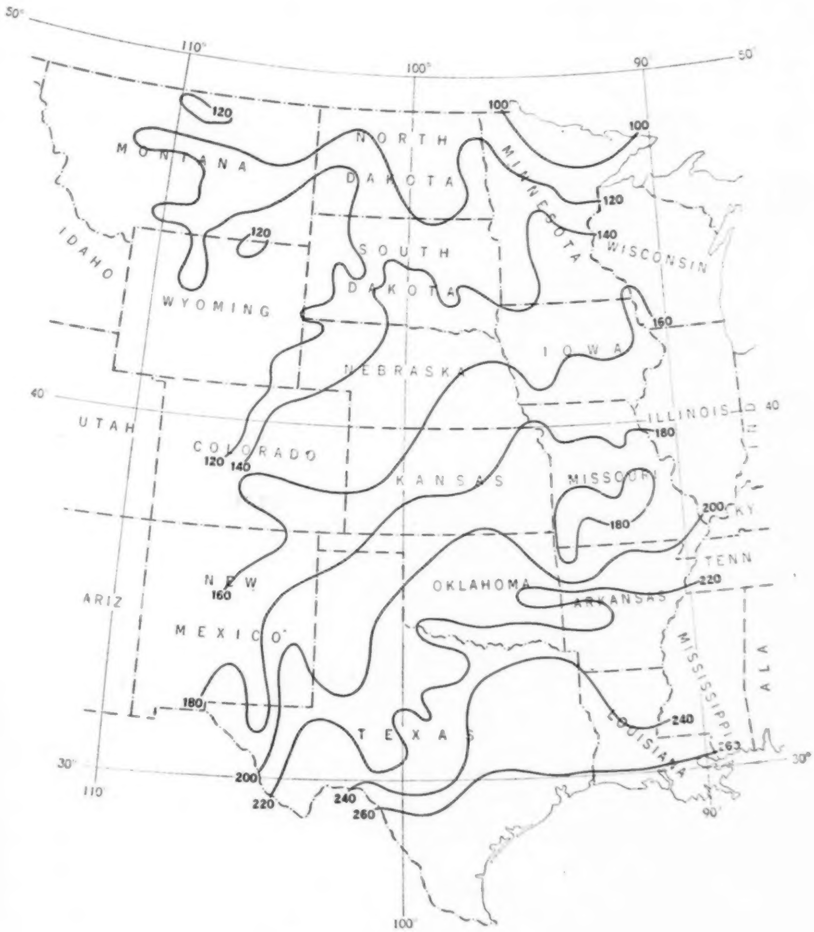

Fig. 6. Average length of the frost-free season over the Great Plains and adjoining sections. (Average number of days from the last killing frost in spring to the first in fall.)

able supply is scanty and summer evaporation, under the influence of comparatively large wind movement, high temperature, and low relative humidity, exacts a heavy moisture toll, particularly in the central and southern portions, while droughts are rather frequent. These inter-operating influences make the moisture problem exceedingly complex, but the final result is a rather frequently insufficient supply for profitable crop growth in a large portion of the region, particularly in the drier sections.

Farming, as ordinarily practiced, or even the so-called dry-farming methods, can never increase production of crops in the less favored localities sufficiently to be a material factor in the total food production of the country, although by careful tilth and fallowing, the more favored portions may contribute, in some measure, to the nation's supply. The drier portions of the region, considered from a climatic standpoint, are pre-eminently grazing areas, and must so remain until moisture is artificially supplied by irrigation.

At present only about one per cent of the Plains is under irrigation, but this can be materially increased and, at some future time, irrigation will doubtless be practiced extensively, where climatic conditions other than rainfall are favorable for intensive crop production. At present, where irrigation is practiced, the water is derived mostly from rivers, but a few sections at least, contain some underground water supplies and the comparatively high wind velocity suggests a cheap means of bringing this into service by harnessing the natural forces that are constantly expending themselves to no good purpose throughout the region. This is especially true for irrigating gardens or small truck plats to assure production of vegetables for family use, thus keeping cash outlay at a minimum.

Annals of the Association of American Geographers
Volume XIII pp. 81-107, Plate III-VIII

THE NATURAL VEGETATION OF THE GREAT PLAINS REGION

H. L. SHANTZ

CONTENTS

The Region Here Considered.—The region considered in this paper (Fig. 1) lies between the Rocky Mountains on the west and the 97th degree of west longitude on the east. On the north it extends to the Canadian boundary and on the south to near the Mexican boundary. The line marking the eastern boundary of this region starts at the 98th degree of west longitude on the Canadian boundary and extends south along the western edge of the Red River valley. From a point west of Fargo, N. Dak. it leaves the Red River Valley and runs south and a little east until it reaches the 97th degree of west longitude in east central Nebraska. It then bends a little to the west and crosses the Oklahoma-Texas boundary at the 98th degree of west longitude. This line swings westward as far as the 99th degree of west longitude in Callahan and McCulloch counties, Texas, and then southeast, reaching the Gulf coast at about the 97th degree of west longitude. The western boundary follows the east side of the Rocky Mountains to the Montana-Wyoming boundary where it turns east to the eastern side of the Big Horn Mountains, extending south to the lower end of the Sangre de Cristo range where it turns west to the Manzano range, and east past the Sacramento, Guadalupe and Santiago mountains, thence east and later north to Fort Stockton, Texas. The western boundary line then runs north and west to the Texas-New Mexico line which it crosses about 50 miles west of the Pecos River. It then runs north to Roswell, New Mexico, where it swings across the Pecos, down the east side and crosses the New Mexico-

Texas state boundary 50 miles east of the Pecos River. The boundary line runs parallel to the Pecos at a distance of about 50 miles east of the river except for a short distance where it touches the Pecos River in Ward and Crane counties in Texas. It then runs parallel to the Rio Grande River for a distance of 50 miles northeast. The boundary line strikes the Rio Grande 60 miles above its mouth.

Correlation of Vegetation with Climatic and Soil Conditions.—Before discussing in detail the plant communities, it is necessary first to present a number of general considerations. The correlation between any single climatic or soil factor and the natural vegetation is often profoundly affected by change in the other factors. Similar distinct differences in the type of vegetation may be caused by any one of a number of factors. In correlating vegetation with conditions of soil or climate this consideration should be kept constantly in mind. When all other factors remain unchanged a close correlation can be made with the changes in any one factor of the environment. A change in either the rainfall, the soil texture, the soil depth, the available soil moisture, or the saturation deficit of the air, will be accompanied by a change in vegetation, if the other factors remain constant. If other factors vary, marked changes in one factor may produce no noticeable effect on the vegetation. The gradual decrease in the quantity of rainfall from east to west may be correlated with a gradual change in the natural vegetation. The greater quantity of rainfall in the south, as compared with the north, may produce no change in type of vegetation. This may be explained by the increase in evaporation and water requirement of the plants in the south as compared with those in the north. Differences in the depth of moist soil or in the available soil moisture may be closely correlated with changes in vegetation, provided the factors which control rate of loss of water do not vary in such a way as to equalize these conditions.

In dealing with plants we are equally concerned with the factors which determine the rate of loss of moisture from the plant and with the total available soil moisture supply. The quantity of rainfall is greater in the southern than in the northern portion of the Great Plains and a deeper layer of soil with moisture available for plant growth is produced. But this increase in moisture supply in the southern part is equalized by the higher water requirement. To produce a ton of dry matter, alfalfa required 518 tons of water at Williston, N. Dak., 630 tons at Newell, S. Dak., 853 tons at Akron, Colo., and 1005 tons at Dalhart, Tex.[1] Field studies of the rate of use of

[1]Briggs, L. J., Shantz, H. L. The water requirement of plants as influenced by environment. 2d Pan-American Scientific Congress, Wash., D. C., Dec. 27, 1915-Jan. 8, 1916. Govt. Printing Office, 1917.

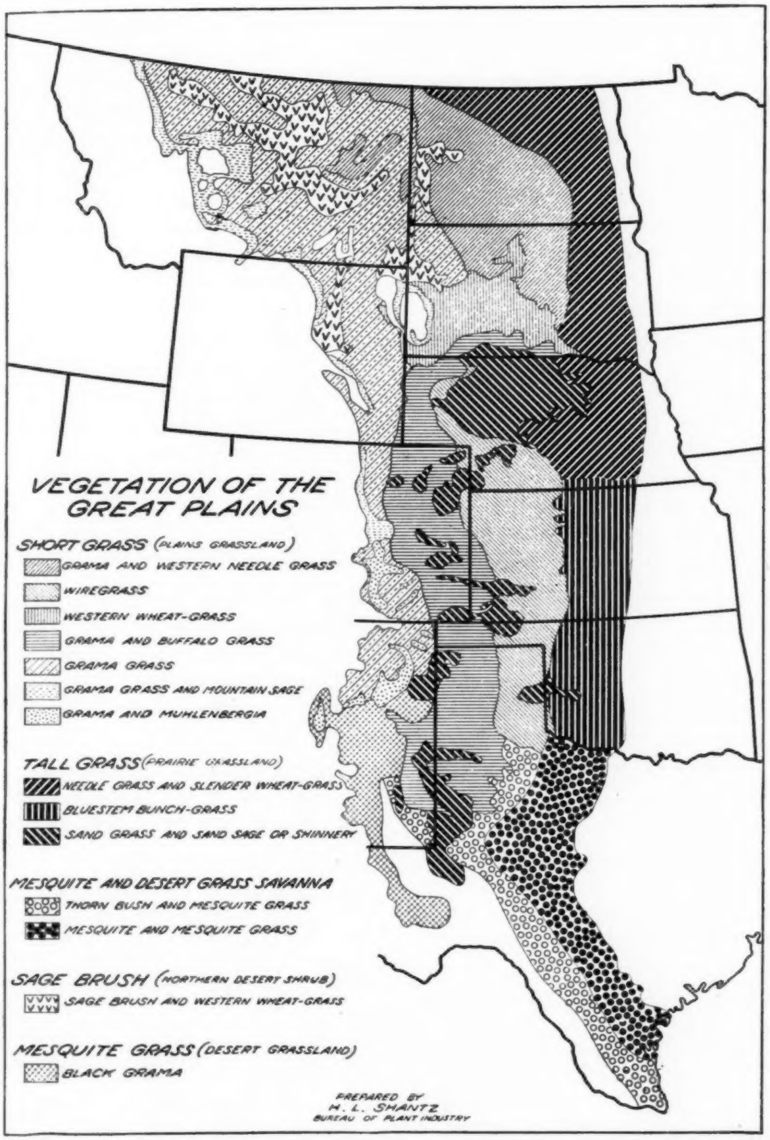

Fig. 1. Sketch map of the Great Plains region showing the areas occupied by the principal plant-communities.*

*In determining the boundary lines in the northwest the writer has been assisted by A. E. Aldous, Classifier, U. S. Geological Survey, and in the location of the sand-hill areas of the south, by C. F. Marbut, Scientist in charge of the U. S. Soil Survey.

water by a crop of spring wheat show the rate to be twice as great in the south as in the north.[2]

A factor of importance for plant growth is the length of the drought period. This is normally long in the south and short in the north. The rapid-growing grasses utilize the short growing period in increasing the vegetative part of the plant and producing seed. These grasses are drought-enduring and thus pass through the long drought-rest period without injury. The habitat factors measured throughout the year do not properly express the condition under which the vegetation develops. Evaporation, for example, is greater during the periods of extreme drought, when the water loss from the plant cover is almost negligible, because there is no water present for it to use. When plants are well supplied with moisture and rapidly transpiring the evaporation is likely to be relatively low. The evaporation measurement expresses potential loss of water. In any given area on the High Plains the evaporation measurement for different periods of the frost-free season is probably more nearly inversely correlated than directly correlated with the actual water loss from the area.

If soils of similar texture are considered, the depth of the layer of periodically moistened soil is an indirect measure of the amount of available soil moisture. Throughout this region the subsoil is permanently dry to a depth of many feet. When rain falls it moistens the surface soil. Not until this is filled to the moisture equivalent, or a little below this percentage, does moisture pass to the soil below. The soil moisture remains near the surface and does not pass down unless additional rains add to the total moisture supply. It is not drawn up to replace the moisture lost from the surface by evaporation. The surface dries but there is no appreciable upward or downward movement of the liquid. Plants rapidly absorb the soil moisture and pass it off into the air by transpiration if the moisture lies within reach of their active roots.

The soil profile, like the vegetation, is a summation of the climatic conditions over a long period of years. Variations in vegetation are not as nearly proportional to total rainfall as variations in soil profile. The increased demand of the plant for moisture in the warmer portions of the Plains, due at least in part to the increased saturation deficit of the warmer air, reduces the efficiency of the soil moisture if measured in terms of plant production. This effect does not operate on the moisture penetration in soils during heavy rains or during periods where the plants are not rapidly absorbing soil moisture.

[2]Cole, John S. and Mathews, O. R. Use of water by spring wheat on the Great Plains. U. S. Dept. Agriculture Bul., No. 1004, 1923.

The profile or depth of soil is not in itself the factor which determines the plant cover. Both the vegetation and the soil profile are determined largely by the same factors, chiefly the parent soil material and the climate.

Under the same climatic condition soil texture modifies the profile profoundly. The profile layers lie deeper in the lighter soils and nearer the surface in the heavy soils. The depth of these layers, especially the layer of carbonate accumulation, can be correlated with the plant cover through the medium of available soil moisture. When this difference in depth is due to variation in soil texture the effect on the plant is due both to the change in the water-holding capacity of each unit of soil and the quantity of total moisture available. A heavy soil will hold one inch of rainfall in the surface 6 or 8 inches. The surface moisture is lost rapidly by evaporation. The soil moisture is readily available to the roots and growth is rapid and luxuriant. The same amount of rainfall would penetrate to a foot or more in sand. Growth would be less rapid since not all of the moisture is available to the roots at the same time and they must be pushed far into the soil to reach the moisture supply. Moisture, within the quantity retained in dry-land soils, does not move to the roots through any considerable distance. The roots must therefore grow to the moisture supply. Consequently more time is consumed and drought delayed much longer in sand than in heavy land. This is true of the cultivated as well as the native crops.

Vegetation has an important reaction on soil profile. In eastern Colorado the layer of carbonate accumulation develops at 14 to 18 inches under a short-grass vegetation. Had there been no vegetation to absorb the soil moisture the layer of carbonate accumulation would never have developed. When the vegetation is destroyed by cultivation the depth of moisture penetration is greatly increased, even if the land is continuously cropped. Alternate cropping greatly increases the penetration of soil moisture[3] and crop plants normally grow in a soil which is moist below the layer of carbonate accumulation. Theoretically the layer of carbonate accumulation would be lowered under cultivation. The depth of soil to the layer of carbonate accumulation is a measure of the depth of moisture penetration under the natural vegetation during all but exceptional years. The soil profile affords,

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[3]Even under conditions of cultivation moisture seldom penetrates below two or three feet and with alternate cropping only rarely is moisture stored to a depth of five or six feet. See Mathews, O. R., " Storage of Water in Soil and its Utilization by Spring Wheat. U. S. Dept. Agriculture, Bul. No. 1139, 1923.

therefore, an indirect measure of the moisture condition during normal years. Unless other factors interfere vegetation and soil profiles can be closely correlated. This correlation is not perfect and the failure to correlate exactly affords an important means of interpreting the habitat.

In drawing general lines of plant distribution it is important that only mature soils of comparable texture be considered. Along the line between the tall grasses and the short grasses if the soil becomes light in texture, sand in other words, the eastern or tall-grass types will push west. A bluestem bunch-grass cover characteristic of a good loam soil in eastern Kansas will entirely disappear from the loam soils farther west and be confined entirely to the sands, on which it extends into the deserts of New Mexico. Where very heavy land occurs in central Kansas it is likely to be characterized by the short grasses, this vegetation type being carried eastward by a heavy soil. The vegetation types are, therefore, carried far out of their natural climatic range by a soil of either heavy or light texture. Bluestem bunch-grass which occupies the well-developed loams with a depth of about three feet will push west on crests where erosion is taking place and where moisture penetrates several feet into the soil. This penetration is due largely to the open spacing of the plants and the reduction in the rate of use of soil moisture. Bluestem bunch-grass is carried west beyond its range by flood water or by a sandy soil, since moisture penetration is relatively deep in both cases. This type occurs even in the blowouts of the heavy clay where clay granules blow about as sand. It is also characteristic of the pure gypsum sand dunes of New Mexico and occurs on eroded areas of caliche in the southern Great Plains. It is, therefore, not the depth of the layer free of carbonate accumulation which determines the growth of this species in central Kansas, but rather the depth of moist soil which is indicated in the well-developed soils by the depth to the layer of carbonate accumulation. On new or eroded soils carbonates may occur at the surface and the moisture condition still be favorable for the grass. Passing eastward from the high plains this type is soon shut out except on sand dunes or sandy land. Here it is evident that sand offers perfect drainage and consequently the best conditions for a relatively xerophytic grass. In the humid east the drainage is perfect in sand dunes, and bluestem bunch-grass succeeds well on sand in Illinois and Indiana, and on the Hempstead Plains of Long Island.[4] Sand to some extent equalizes the habitat. In the arid country it furnishes

[4]Harper, Roland M. Some dynamic studies of Long Island vegetation. Plant World, v. 21, No. 2, 1918.

the most favorable moisture condition, and in the more humid country the perfect drainage affords a favorable habitat for the xerophytic grasses. In short, the widest distribution from humid to dry habitat occurs on sand. Clay will often carry western types, especially short grasses, some distance east. The line of demarcation between the short-grass and the tall-grass vegetation must be swung east on heavy soils, and west on sands.

In making a generalized map of the plant associations it is necessary to recognize clearly the successional stages initiated by overgrazing or breaking. Before the vegetation can be successfully correlated with agricultural potentialities, successional and climax stages must be clearly recognized. Undeveloped sand dunes or areas of very young soils are characterized by a successional stage of vegetation. The sand hills on the Great Plains are constantly tending toward the normal short-grass type of the region. The soil profile enables one to discern clearly old and new soils. Climax types of vegetation occur only on older soils, those soils which have come into equilibrium with the climatic conditions. The soil profile affords a valuable means by which to determine whether the vegetation is a climax or merely a successional stage.

There are then two methods of evaluating the habitat, namely, by the proper interpretation of the vegetation and by the proper interpretation of the soil profile. The soil profile as an aid to the study of vegetation is now made available to the botanists in this country through the work of the Bureau of Soils[5] and should greatly influence future study of vegetation.

From the considerations above it is clear that, in outlining on a generalized map, areas characterized by different types of vegetation, the occurrence of the type on mature soil, soil with a well-developed profile, should first be considered. These types of vegetation are climax types which have come into equilibrium with the soil and climatic conditions. Since a light soil or a heavy soil modifies the soil profile and the vegetation, it is well, if climatic climax vegetation areas are being outlined, to consider chiefly the vegetation which occurs on well-developed loam soils. Breaking destroys the vegetation and overgrazing often modifies it profoundly. It is therefore necessary to take these factors into consideration in deciding which type represents the original vegetation. These precautions are especially necessary in regions where most of the original vegetation has been destroyed. Failure to recognize the stages of succession would often lead to erroneous estimates of the importance of different communities.

[5]See Marbut, C. F., in this number of the Annals.

THE PLANT COMMUNITIES.—The vegetation of the region here outlined is not uniform. Along the eastern edge in any portion north of the Canadian River the grasses are relatively tall and the area resembles a luxuriant meadow. Farther west the tall grasses disappear and the short grasses predominate. The short grasses resemble a well-grazed pasture. South of the Canadian River a scattered growth of trees over a relatively short-grass cover presents the appearance of an orchard of small fruit trees. In the southwest the grass cover may become sparse and the appearance is that of a desert grassland. In the northwest plants characteristic of the great desert push east on the poorer land and produce a vegetation consisting of scattered grasses and shrubs.

The region considered in this paper extends too far east and too far south to be regarded as a natural vegetational unit. It includes within its boundaries parts of the following plant formations and minor communities.

Short Grass (*Plains Grassland*).[*]—Grama grass (association), grama and buffalo grass (association), grama and western needle grass (association), wire-grass (association), western wheat-grass (association), grama grass and mountain sage (associes), grama and Muhlenbergia (associes).

Tall Grass (*Prairie Grassland*).[a]—Needle grass and slender wheat-grass (association), bluestem bunch-grass (association), sand grass and sand-sage (associes), shinnery (associes).

Mesquite and Desert-Grass Savanna (*Desert Savanna*).[b]—Mesquite and mesquite grass (association), thorn bush and mesquite grass (associes).

Sagebrush (*Northern Desert Shrub*).[c]—Sagebrush and western wheat-grass (associes).

Mesquite Grass (*Desert Grassland*).[d]—Black grama (association).

Four criteria may be used in separating the formations, namely: physiognomy or general appearance, floristic composition, develop-

[*]A small portion of this grassland which pushes across the highlands of N. Mex., Ariz. and into Utah, is not included.

[a]Here are included only the two western associations and two developmental phases (associes) which push west on sandhills.

[b]The greater part of this community is included here, but it does not cover extensive areas in the United States.

[c]Only a few outstanding developmental areas of this type are included. These have pushed from the deserts into the Great Plains in Montana and Wyoming.

[d]Only part of one association located at the eastern edge of the formation is here included.

ment of vegetation or succession within each area, and environmental conditions or the habitat.

Short Grass (*Plains Grassland*).—The typical appearance of this grassland as a whole is that of a closely pastured meadow. Except during years of more than normal rainfall the taller growing plants are almost entirely absent, and the vegetation presents the appearance of extreme monotony. There is little variation in appearance from north to south or east to west. Changes in the vegetation within the area are due largely to differences in soil texture, run-off or flood-water irrigation which affect the available soil moisture supply.

The transition to the tall-grass formation is gradual on the east where many of the taller plants occur. On the west many species characteristic of the foot-hill region enter and modify the pure short-grass cover which is characteristic of the central portion of the area.

In spring the short grasses start growth as soon as temperature conditions are favorable. Many flowering plants vary the monotony of the short-grass cover. If the season is unusually dry these plants are usually inconspicuous, and even the short grasses may fail to put up flower stalks. If the season is unusually moist annuals and herbaceous perennials often become a prominent component of the vegetation.

In botanical composition the area varies considerably and several associations may be recognized. By far the most important plant is grama grass (*Bouteloua gracilis*), which occurs throughout the extent of this formation. Buffalo grass (*Bulbilis dactyloides*) does not occur in the north and west portions of the area, but is much more important than any other species with the exception of grama grass. In the northeast western needle-grass (*Stipa comata*) and western wheat-grass (*Agropyron smithii*) are important, while in the east wire-grass (*Aristida longiseta*) often becomes a prominent feature. Along the western border nigger wool (*Carex filifolia*) and mountain sage (*Artemisia frigida*) are often important, and in the southwest matchweed (*Gutierrezia sarothrae*) becomes equally important. Among the plants not considered as dominating associations but very prominent in the vegetation are the perennials *Koeleria cristata*, *Sporobolus cryptandrus*, *Schedonnardus paniculatus*, *Psoralea tenuiflora*, *P. argophylla*, and the annuals *Festuca octoflora*, *Plantago purshii*, *Boebera papposa*, *Leptilon canadense*, *Helianthus annuus*, *Lappula occidentalis*, and *Hedeoma nana*. During favorable years gum weed (*Grindelia squarrosa*) becomes prominent, although this plant requires an unusual combination of two favorable seasons for its best development. In the southern portion it may grow as a perennial, the old stems putting out branches from the base during the third season.

The short grass formation is typical for the Great Plains. Along the Canadian boundary it occurs from western North Dakota across Montana to the Rocky Mountains. It extends in a broad band down across the Great Plains and almost to the southern escarpment of the High Plains in Texas. On the west its boundary is the same as that of the total region here considered (Fig. 1). On the east it follows rather closely the 2000-foot contour. In the north this boundary line starts between the 102d and the 103d degree west longitude and runs southeast just west of the Mouse River Valley and crosses the North Dakota and South Dakota boundary just east of the 99th degree of west longitude. From this point it runs south and a little west and strikes the Missouri River in the southern part of Brule county, South Dakota. The boundary then swings west around the great sand-hill area of Nebraska, then southeast and south across Kansas a little west of the 99th degree of west longitude, bending westward and extending south along the east boundary of the "Panhandle" of Texas. In Texas the short-grass formation is limited to the "Panhandle" and the southern portion of the High Plains. In eastern New Mexico it is also limited to the High Plains and to portions of northeastern New Mexico. Within this area there occur large tracts of sand hills dominated by tall grasses, and areas of poor soil and low rainfall in the northwest dominated by sagebrush and western wheat-grass.

Overgrazing or breaking destroys the plant cover and initiates a succession leading to the reestablishment of the original vegetation. This succession varies somewhat in different parts of the area. The following stages may be recognized: (1) an annual-weed stage consisting of *Boebera papposa, Plantago purshii, Salsola pestifer, Verbena bractiosa, Lappula occidentale* and *Hedeoma nana,* or similar plants; (2) a perennial stage consisting chiefly of mountain sage (*Artemisia frigida*) in the north, or matchweed (*Gutierrezia sarothrae*) in the south, or wire-grass (*Aristida longiseta*) in the east, all nearly valueless for grazing; (3) the short grass reestablished in a period of 30 to 60 years.

As a rule the vegetation starts growth when suitable temperatures occur in the spring. The frost-free period is short in the north (80 to 120 days) and long in Texas (210 days). Seasonal growth, although usually initiated by suitable temperature, is seldom terminated by low temperature.

The rainfall decreases from east to west and from south to north, ranging in the north in portions of Montana to 15 inches, while in the eastern portion in Nebraska, Kansas, Oklahoma, and Texas it ranges from 25 to 30 inches.

Over the whole of this area the layer of periodically moist soil is shallow. This is especially true in the northern and western portions where the layer of carbonate accumulation lies at a depth of from 8 to 18 inches. In the southern and eastern portions the soil may be two feet in depth. Beneath this there is a layer of carbonate accumulation and a dry subsoil. In the southern portion this layer of carbonate accumulation has developed into caliche, forming a rock-like layer beneath the surface soil. The moisture available for growth in this formation at the beginning of the growing season seldom exceeds that held in the first 1 or 2 feet of soil, or the equivalent of 2 or 3 inches of rainfall. The stored soil moisture and the rainfall of spring and early summer enable growth to continue until early in July. At that time practically all of the stored water and that added by the rains has been consumed. The plants then pass into a drought-rest condition which may be broken occasionally by summer or fall rains. During exceptionally wet years, growth may continue almost without interruption throughout the whole season. In extremely dry years, the period during which moisture is available in the soil may be so short that even the buffalo grass, which can flower within 30 days, is prevented from flowering. The dominant species of this formation are without exception drought-enduring plants. They are able to grow rapidly during periods when moisture is available and to pass into a dormant condition when drought occurs. They resume growth quickly when moisture is again supplied. The majority of the annuals can ripen seed during a very short season of growth and are able to produce a few seeds even during the drier years. In such years the plants are depauperate. During wet seasons these annuals may form an extensive portion of the vegetation cover.

Available moisture is about twice as great in the southeast as in the northwest. The evaporation for the six months from April to September, inclusive, from a water tank 2 feet deep and 6 feet across, buried to the soil level, varies from 33 inches in the north to 50 inches in the south.

The moisture requirement of the plants is about twice as great in the south as in the north, but, since the moisture supply is also greater, the moisture conditions for the growth of native plants are much the same.

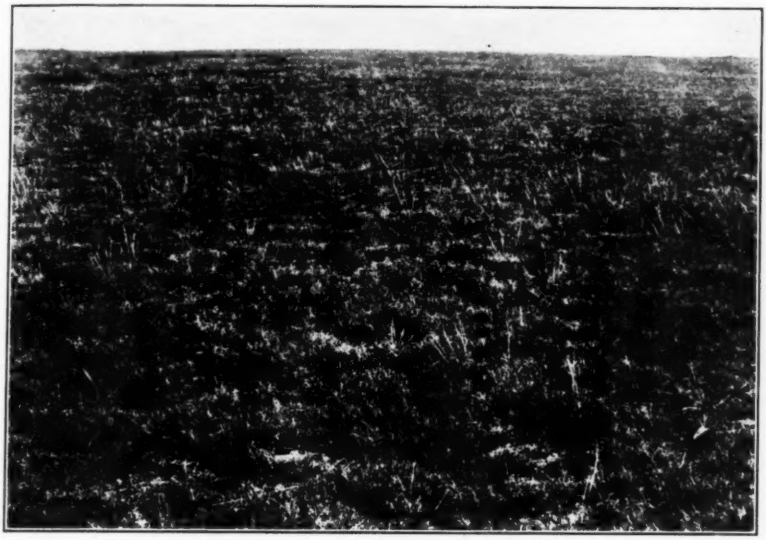
In this formation we may recognize the following principal plant associations: Grama grass (association), grama and buffalo grass (association), grama and western needle grass (association), wire-grass (association), western wheat-grass (association), grama grass and mountain sage (associes), grama and Muhlenbergia (associes).

The grama-grass association dominates the northwest portion and extends in a rather narrow zone along the east face of the mountains. The grama and buffalo-grass association, characterizes the central and southern Great Plains, and extends from South Dakota across the plateau region of Texas. The grama and western-needle-grass association occupies the northeast portion and is most prominent in North Dakota and South Dakota. The wire-grass association extends across Nebraska, Kansas, Oklahoma, and the eastern portion of the "Panhandle" of Texas. The western-wheat-grass association is most extensively developed in the northern portion, especially in South Dakota on the Pierre shales, where it occurs over extensive areas. The grama-grass and mountain-sage associes, may be recognized skirting the mountains, dominated largely by grama grass with an admixture of nigger wool (*Carex filifolia*) and mountain sage (*Artemisia frigida*), and many other species which characterize the eastern foot-hills of the Rockies. This is not an extensive community and is more or less mixed because much of the area over which it is growing has not reached a stable condition. The soils have not yet developed their profile, and the whole area may be considered as indicating a slow and gradual successional change. In some of the drier valleys of Colorado and New Mexico grama grass is mixed with or gives place to Muhlenbergia to form the grama and Muhlenbergia associes.

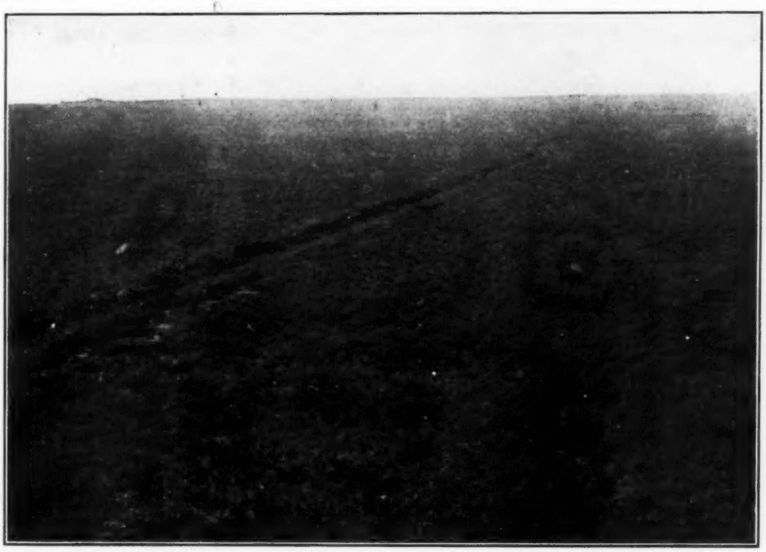
Grama-grass association (Pl. IIIa)—The dominant plant in this association is grama grass (*Bouteloua gracilis*). With this there are also found in many places *Carex filifolia, C. stenophylla, Koeleria cristata,* and a wide range of herbaceous plants, such as *Artemisia frigida* and *Phlox hoodii,* in the north, and *Gutierrezia sarothrae* in the south. In general appearance it is typical short-grass land.

The area occupied by this association forms a wedge, very broad in the north and very narrow in the south, lying just east of the mountains. In Montana it extends from the mountains on the west to the eastern boundary of the state, but in Colorado forms only a narrow band.

This grassland occupies a soil which is very shallow, ranging in depth from 8 to 18 inches to the layer of carbonate accumulation, below which is a permanently dry subsoil. The soil moisture available during normal years is equivalent to from 1½ to 2½ inches in rainfall, the supply being replenished by occasional rains during the period of plant growth. The moisture supply is lowest in the north and increases somewhat to the southward. Rainfall ranges from 15 to 20 inches. The period free from killing frost is relatively short, from 80 to 150 days. The evaporation ranges from 33 inches in the north



a. Grama grass association (short grass). *Bouteloua gracilis* with *Carex filiofolia* and an occasional plant of *Stipa comata*. Glendive, Montana, August 22, 1916.



b. Grama and buffalo grass association (short grass). A pure stand of *Bouteloua gracilis* and *Bulbilis dactyloides*. Sharon Springs, Colo., Oct. 5, 1922.

to 50 inches in the south. The growth period is generally terminated by drought. There is no storage of water from year to year, and only during years of exceptional rainfall does water penetrate the soil below the layer of carbonate accumulation. It is excellent grazing land with a carrying capacity of from 15 to 30 cattle per section. During years of more than normal rainfall, land characterized by this association produces excellent small-grain crops.

Grama and buffalo-grass association (Pl. IIIb.)—The grama and buffalo-grass association is typical of the High Plains. The plant cover is often uniform and covers the ground with an open or dense mat-like growth. During wet years the short grass flowers and many annuals and perennials become prominent in the plant cover. It is dominated by almost equal quantities of grama grass (*Bouteloua gracilis*) and buffalo grass (*Bulbilis dactyloides*). Often the cover is almost pure but at other times there are mixed with these grasses many small annuals (such as *Plantago purshii, Festuca octoflora, Hedeoma nana* and *Lappula occidentale*). During years of more than normal rainfall, other and more prominent plants, such as *Leptilon canadense, Grindelia squarrosa, Stipa comata,* and *Sporobolus cryptandrus,* are prominent.

This association extends from South Dakota across western Nebraska, eastern Colorado, southwestern Kansas, northeastern New Mexico, western Oklahoma, and northwestern Texas.

The rainfall over this area is somewhat higher than over the grama-grass area and ranges from 15 to 20 inches. Evaporation measurements vary from 35 to 55 inches. The soil is not as shallow as under grama grass, the depth to the layer of carbonate accumulation ranging from 14 to 18 inches. The soil moisture stored in the soil at the beginning of the growth season amounts to the equivalent of from 2 to 3 inches, except during abnormally dry or abnormally wet years. The water requirement of plants is relatively high in this association. Alfalfa to produce a ton of dry matter requires in this association in eastern Colorado about 800 tons of water, and in the same association in Texas from 1,000 to 1,400 tons of water. The frost-free period is from 120 to 210 days in duration. The period of growth, however, is often as short as from 30 to 60 days on account of drought. The better types of land where rainfall is supplemented to some extent by drainage water within this area are marked by the occurrence of plants characteristic of the wire-grass association. This condition occurs in many places where alluvial soil is collecting and the moist soil is deeper.

Soil moisture records for the native vegetation extending over a period of 9 years at Akron, Colo., show available moisture in the third

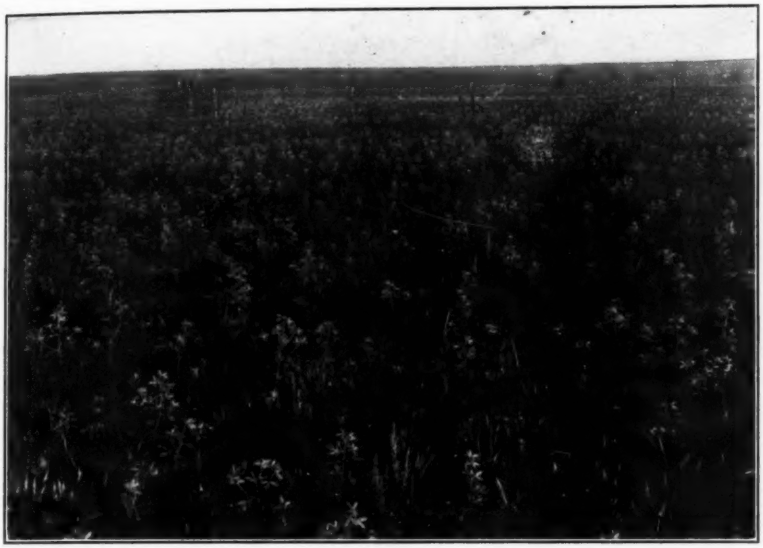
foot of soil only once during this period. During several years no available moisture was recorded in the second foot. A four-year record at Amarillo, Texas, indicates about the same conditions of soil moisture under the native sod.

This association furnishes excellent grazing land with a carrying capacity of from 20 to 40 head of cattle per section. Crop production is good during years of more than normal rainfall. In the north small grains do fairly well in medium or wet years, but fail in dry years. Sorghum and short-season corn are grown, and in the south a small quantity of cotton has been produced.

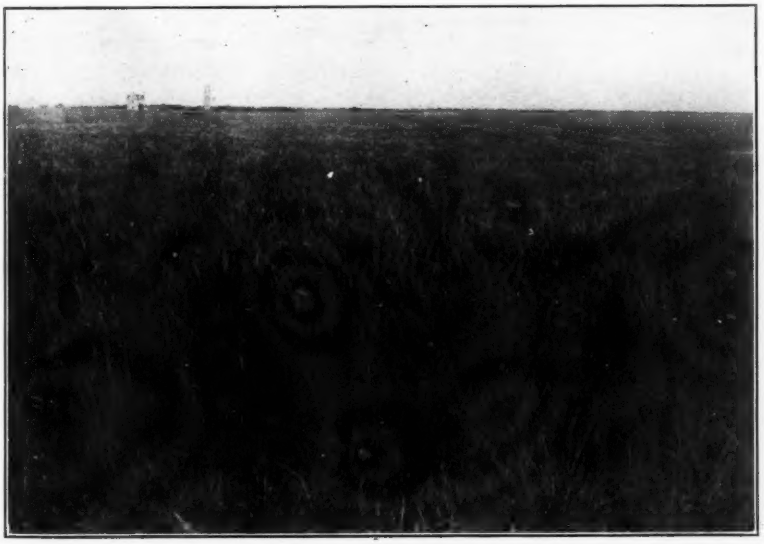
Grama and western-needle-grass association (Pl. IVa.)—The appearance of this association is much more varied than that of almost any other portion of the short-grass formation. Except during years of extreme drought the plant cover does not look like a mat of short grasses. The short grasses are important but are overtopped by taller grasses and herbaceous plants. The association is dominated by grama-grass (*Bouteloua gracilis*) mixed with western needle grass (*Stipa comata*). With these dominant grasses there occur other important grasses and many herbs such as *Psoralea argophylla* and *Eschinacea angustifolia.*

This association occupies the southwestern half of North Dakota. Isolated areas occur in Montana, and in the northern part of South Dakota occupying a relatively large area both east and west of the Missouri River.

This plant association is limited to an area receiving from 15 to 20 inches of rainfall. Over the area evaporation is relatively low, probably ranging from 30 to 35 inches. The soil is relatively dark with the layer of carbonate accumulation at from 18 to 24 inches below the surface. The moisture storage at the beginning of the growth season is nearly as high as in any other portion of the short-grass cover, being equivalent to 3 or 3½ inches of rainfall. The frost-free period is short, from 90 to 150 days. As a rule the growth of vegetation which begins with the approach of suitable temperature conditions in the spring is terminated in July or August by the complete exhaustion of the available moisture supply. Two factors combine to make the area occupied by this association the best of any in the short-grass formation for crop production: first, a rainfall sufficient to moisten the soil to a depth of 20 to 30 inches; second, a cool climate which keeps down the excessive loss of water by evaporation or transpiration. The water requirement of plants in this section is relatively low. Alfalfa requires 500 to 800 tons of water in this area to produce a ton of dry matter.



a. Grama and western needle grass association (short grass). A good cover of *Bouteloua gracilis* and *Stipa comata*. Prominent plants are *Psoralea argophylla*, *Artemisia dracunculoides*, *Polygala alba*, *Artemisia frigida* and *Echinacea angustifolia*. Mandan, N. Dak., July 15, 1915.



b. Wire-grass association (short grass). A rather dense stand of *Aristida longiseta* with *Bulbilis dactyloides* and *Bouteloua gracilis* forming a sod cover underneath. Hays, Kan., June 29, 1918.

This association affords excellent grazing and has a carrying capacity of from 20 to 60 cattle per section. It characterizes the best wheat land in the short-grass formation, land which can be relied upon to produce good crops during all but the drier years.

Wire-grass association (Pl. IVb.)—In appearance the wire-grass association is more varied than the typical short-grass cover. The ground is covered by a mat of short grasses. Overtopping this mat the wire-grass and other taller plants may become so dense as to obscure the short grasses entirely.

The wire-grass association is an abbreviated name for what in full should be grama and buffalo and wire-grass association. Both grama grass(*Bouteloua gracilis*) and buffalo grass (*Bulbilis dactyloides*) are grasses of great importance in this area, but with these there occurs a relatively even stand of wire-grass (*Aristida longiseta*). This association is a more luxuriant eastern phase of the grama and buffalo-grass association.

This association lies between the grama and buffalo-grass association on the west and the bluestem-bunch-grass association of the tall-grass formation on the east. The most extensive areas are in southwest Nebraska, western Kansas, the eastern portion of the "Panhandle" of Texas, and the intermediate area in Oklahoma.

This plant association characterizes an area in the central portions of the Great Plains where the frost-free period ranges from 120 to 220 days. The soil is much deeper to the layer of carbonate accumulation than in the grama and buffalo-grass association. The soils are chestnut brown with the layer of carbonate accumulation at a depth of from 18 to 30 inches. Rainfall is approximately 18 to 22 inches and the evaporation from 40 to 55 inches. The quantity of water stored in the soil at the beginning of the growth season is greater over this area than over the grama and buffalo-grass area and may amount to the equivalent of from 2½ to 3½ inches of rainfall. Water is not stored from one season to the next and almost every year the entire available supply is exhausted during the month of July when the plants pass into a drought-rest condition.

As grazing land this is little better than grama and buffalo grass. Much of the land in this area is crop land. The principal crops are corn in the northern part, winter wheat in Kansas and Oklahoma, some barley in parts of Kansas, and grain sorghum farther south, especially in eastern Texas. This region is one in which crop production is unusually good during favorable years, but in which crop failures are the rule during years of less than normal rainfall. As compared with the grama-grass and western-needle-grass area of the north it has

a higher rainfall and deeper soil; but the warmer temperature, higher rate of evaporation, and greater water requirement of crops, more than equalize the situation, so that crops are grown here under more extreme conditions than they are in the northern area.

Western-wheat-grass association (Pl. Va.)—The western-wheat-grass association is not as varied in appearance as the grama and western-needle-grass association. During years of drought wheat-grass makes little or no growth and the whole area may appear to be dominated by short grasses. During normal years, or years of more than normal rainfall, wheat-grass develops to give the area the appearance of a thinly planted grain field with short grasses forming a mat-like cover over the surface of the ground.

This association, in its typical form, consists of a dense cover of grama grass (*Bouteloua gracilis*) and buffalo grass (*Bulbilis dactyloides*) through which there is evenly scattered a growth of western wheat-grass (*Agropyron smithii*). A complete designation of the area would be grama and buffalo and western-wheat-grass association. This association is limited largely to the Pierre clays of South Dakota. In these clays moisture penetrates slowly and carbonates accumulate at a depth of from 14 to 24 inches. The high water-retaining power of the clay is detrimental to the storage of water since it limits the penetration to the surface layer where it is rapidly absorbed by plant roots or evaporated into the air. Consequently conditions cannot be regarded as favorable for continued growth on these heavy soils as on adjacent loam lands. In certain sections where the soil becomes alkaline the wheat-grass may occur with little or none of the short-grass cover. Such areas should not be confused with the one under discussion, since the conditions are entirely different. They will be discussed under the sagebrush and western-wheat-grass associes. The rainfall over the wheat-grass area ranges for the most part from 15 to 20 inches. During years of heavy rainfall the quantity of moisture is sufficient not only to mature the short grass but also to enable the wheat-grass to make good growth and ripen seeds. Usually drought occurs in midsummer and the whole area passes into drought-rest condition in late summer and autumn. The growth period is therefore determined by water supply and not by temperature, for the frost-free period is long, ranging from 120 to 150 days. Evaporation in this area is relatively low, 35 to 40 inches. The soil is very rich and during years of more than normal rainfall will produce excellent crops of cereals. The heavy character of the soil is conducive during dry years to extreme conditions, during which crop production is precarious and the production of native forage greatly lessened. The water re-

a. Western wheat-grass association (short grass). A good cover of *Bouteloua gracilis* and *Bulbilis dactyloides,* and a relatively good stand of western wheat-grass (*Agropyron smithii*). The hay cut from this type consists largely of western wheat-grass. Philip, So. Dak., July 21, 1908.

b. Grama and Muhlenbergia association (short grass). A practically pure stand of *Muhlenbergia gracillima.* Near Pueblo, Colo., Oct. 10, 1922.

quirement throughout this area is relatively higher than in the grama-grass or grama-stipa areas to the north and considerably lower than in the grama-buffalo or wire-grass areas to the south. It is excellent grazing land and will carry from 30 to 75 cattle per section.

Grama-grass and mountain-sage associes.—Along the mountain front grama grass (*Bouteloua gracilis*) is often mixed with a great variety of plants which are more typical of the mountain grasslands. Among these may be mentioned *Artemisia frigida, Carex filifolia, Achillea millefolium*, Eriogonums of various species, Pentstemons, wild roses, and lupines. These characterize an area in which the rainfall is greater than that of the adjacent grama-grass land. The soils are often not well developed but consist of loose granitic gravels. Where land is level and favorable for cultivation conditions are much better than in the grama-grass areas farther east. With this type may be thrown such outstanding areas as the Judith Basin where, on account of peculiar topography, the rainfall is sufficiently high to develop a good soil and make crop production relatively secure. Small grains are the chief crops grown in this area. As grazing land it will carry from 20 to 30 cattle per section.

Grama and Muhlenbergia associes (Pl. Vb.)—In the southeastern portion of the region considered in this paper, especially in Colorado and New Mexico, near the mountains, conditions become so extreme as to temperature and drought, that grama grass gives way to *Muhlenbergia gracillima.* With this often occurs the cane cactus (*Opuntia arborescens*). This associes characterizes land of inferior production, even as grazing land, and of doubtful value for crop production.

Tall Grass (Prairie Grassland).—The region here considered includes only the western portion of this great grassland. The formation as a whole characterizes the great prairie region of the Mississippi Valley. The area is dominated by tall, luxuriant and relatively deep-rooted[6] grasses. With these are associated a large variety of herbaceous flowering plants. During spring the prairie is a veritable flower garden, but grasses are dominant over the whole area.

The portion considered in this paper forms a broad belt from north to the south across the east side of the region. In the north it extends across almost the whole of the North Dakota boundary. The western boundary has been defined as the eastern boundary of the short-grass formation (see p. 89) and the eastern boundary as the eastern boundary of the region (see p 90). The sand dunes within the area characterized by short grasses are included in the tall-grass formation.

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[6]Weaver, John E., Root Development in the Grassland Formation. Carnegie Institution of Washington, Publication No. 292, 151p., 23 pl., illus. 1920.

A Comparison of the Tall-Grass and Short-Grass Formation.—The great grassland which extends across the Mississippi Valley from the forests of the east to the foothills of the Rockies may conveniently be divided into the tall-grass formation or prairie grassland, and the short-grass formation or plains grassland.

The general character of growth habit of the dominant plants serves to differentiate these two areas. The typical form in the plains grassland is the grama grass, a low-growing plant which puts up comparatively weak and short flower stalks. Only a few scattered taller grasses occur in this formation. As a whole the area is characterized by the mats of short grasses between which are areas of bare soil. In the prairie grassland the grasses are tall with prominent flower stalks. They never produce the low mat-like cover characteristic of the plains grassland, but a sod or bunch-like growth. The prairie is a relatively tall wheat-grass or bluestem grassland, while the plain is a short buffalo and grama-grass or grama-grass land. In general appearance the vegetation of the plains resembles a closely pastured field, while that of the prairie resembles a relatively luxuriant meadow.

From the east to the west in the central region of the great prairies the composition of the plant cover shows a gradual change accompanied by a lessened moisture supply. *Andropogon furcatus, Sorghastrum nutans* and *Panicum virgatum* become less abundant at the eastern boundary of the region considered in this paper and bluestem bunch-grass becomes more dominant. Farther west bluestem bunch-grass gives way to buffalo grass and grama grass. In the north slender wheat-grass and needle grass give way to grama grass. Here the division line is drawn which separates the prairie grassland (tall grass) from the plains grassland (short grass). The causes of this difference in plant cover are differences in the habitat. The most important factors in bringing about this change in vegetation are the quantity of soil moisture supplied by the rainfall and the length of time during which soil moisture is available. The length of the growing season is determined almost entirely by the available moisture.

The development of the vegetation in the short-grass and the tall-grass formation is not the same. Disturbed areas or areas of new land, if located in the short-grass area, may at first be occupied by tall grasses, but are finally dominated by short grasses. Areas of short grass occurring on heavy land or on overgrazed land within the prairie area, if left undisturbed, develop into tall grass.

The boundary between the prairies and the plains as here defined does not coincide with a topographic boundary. No greater topographic change is encountered in crossing it than is encountered in

traveling a similar distance within either the prairies or the plains. The boundary line lies near the 2000 feet contour.

On the basis of soils (Fig. 2) the divisional line is much sharper, but here also the change is gradual. The division line between the short grass and tall grass corresponds to rather sharp soil differences and marks the western edge of the chernozem zone. The plant distribution is correlated with the depth below the surface of the layer of

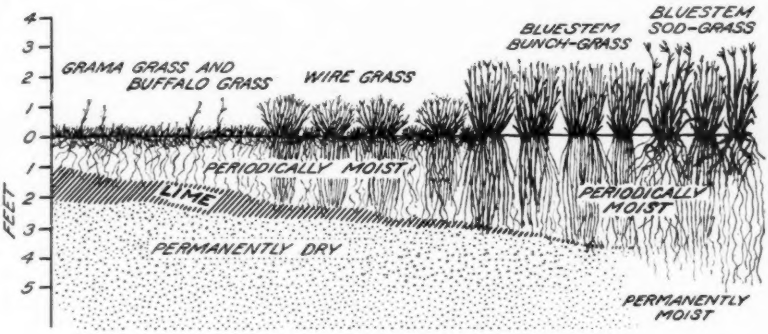


FIG. 2. A sketch showing the relation of the plant communities to the depth of penetration of soil moisture and to the layer of carbonate accumulation. The boundary between the short grass and the long grass formations is drawn where the wire grass is replaced by bunch grass.

carbonate accumulation. Where this depth is less than two feet, the plains type of vegetation predominates. Where greater than about 30 inches, or where lacking entirely, the prairie type of grassland occurs. The important point here is the depth of soil periodically moistened by rainfall and the total moisture supply available. Short grass characterizes areas where each season all available soil moisture is consumed by plant growth. All available soil moisture is also consumed along the western edge of the tall grass in the area considered in this paper. Over the tall-grass area as a whole, however, moisture during the rainy period penetrates so deep into the soil that it is not all recovered and brought to the surface by the plants. Consequently the carbonates are carried down and away entirely with the drainage water. At the beginning of the growth period the soil is moist to the layer of carbonate accumulation, the equivalent of from 4 to 6 inches of rainfall in the tall grass and from 2 to 4 inches in the short grass.

By far the sharpest soil boundary line, that of the disappearance of the layer of carbonate accumulation in the subsoil (Fig. 2), lies well within the area characterized as prairie grassland. This soil boundary

corresponds in a general way with the eastern boundary of the two tall-grass associations considered in this paper. Here the moisture penetrates below the reach of plant roots. Under these conditions there is no dry subsoil between the moist surface soil and the water table. The soil moisture supply is great enough to support a tree vegetation, but on account of the drought of the autumn and late summer, grass fires sweep the area and destroy the young trees as rapidly as they are produced. Farther west where the moisture penetration extends to a few feet only in depth, where the subsoil is permanently dry and there is a distinct accumulation of carbonates at a depth varying from 2 to 4 feet below the soil surface, the tall grasses still find sufficient moisture to maintain themselves. This is a true grassland, a prairie not dependent on fire probably for its maintenance. To the west as the depth of soil moisture becomes less than 2 feet and the tall grasses disappear because of insufficient moisture supply; this is due directly to decreased rainfall and indirectly to the competition of the short grasses. In general, the short grass grows on a shallow soil with a layer of carbonate accumulation at a depth of 1 to 2 feet. The vegetation boundary between the tall grass and the short grass formation is of great agricultural importance since it separates the highly productive farm lands of the prairie from the less productive ranch lands of the plains except where it swings west around sand hills.

Four divisions which occur within the area here considered may be recognized in the tall-grass cover:

Needle grass and slender wheat-grass (association)
Bluestem bunch-grass (association)
Sand-grass and sand-sage (associes)
Shinnery (associes)

Needle-grass and slender-wheel-grass association (Pl. VIa.)—The needle-grass and slender-wheat-grass association is characterized by grasses of moderate height and by many prairie herbs. The grasses do not turn red as do the Andropogons farther east and south. Their appearance is that of a relatively luxuriant meadow of grasses with slender flower stalks. The chief grasses are needle grass (*Stipa spartea*) and slender-wheat-grass (*Agropyron tenerum*).

This association occupies most of eastern Nebraska, South Dakota and northern and eastern North Dakota. Along the eastern boundary which lies near the 97th degree of west longitude this type is replaced by the tall Andropogons of the Andropogon sod association. On the south the bluestem-bunch-grass association replaces it just north of the Nebraska-Kansas boundary.

a. Needle grass and slender wheat-grass association (tall grass). A good stand of *Agropyron tenerum* and *Stipa spartea*. Edgley, No. Dak., Aug. 1918.

b. Bluestem bunch-grass association (tall grass). Typical close stand of bunch grass on sand land, far west of the typical range of this association. Southeast of Yuma, Colo., Sept. 12, 1908.

In this association the plants start growth early in the spring, as soon as temperature conditions are favorable, and continue usually until late in July, when droughts occur. This grassland characterizes a relatively heavy soil. The soil is black and 3 feet or more in depth to the layer of carbonate accumulation. During the early part of the growing season the soil may hold in storage as available moisture the equivalent of 5 inches of rainfall. The region as a whole has a relatively short frost-free period, ranging from 100 to 170 days. The growth period, even in this section, is usually terminated by drought, the total soil-moisture supply being consumed by the grass cover. There is consequently no storage of moisture in the soil and no drainage through the subsoil to the water table below. The evaporation in this region is relatively low. Few measurements have been made but the range is probably from about 30 to 40 inches. Rainfall ranges from 15 to 20 inches in the northern and from 20 to 30 inches in the southern part of the area. This type of vegetation characterizes land which has proved highly productive. On the basis of the value of all crops[7] this type of vegetation is designated by the areas of high production in eastern North Dakota, South Dakota, and Nebraska. The chief crop in the southern portion is corn, and in the northern portion spring wheat. Oats, barley, and rye are also important crops in the northern part of the area. It characterizes, more than any other type here considered, the region best suited to spring wheat. This association furnishes excellent grazing land of high carrying capacity.

Bluestem-bunch-grass association (Pl. VIb.)—This association is characterized by bluestem bunch-grass (*Andropogon scoparius*). Where the grass forms a dense stand the whole area has the appearance of a grain field. The color is very dark when looking toward the wind, but very light when looking with the wind. Often the bunches stand some distance apart and the interspaces are occupied by shorter grasses or herbaceous plants. In general appearance this grassland is vastly different from that of the needle grass and slender wheat grass. Early in summer the grasses take on a reddish-brown hue and remain in this condition throughout the early autumn and winter unless previously grazed or cut for hay. It occupies a broad belt extending south from southern Nebraska across central Kansas and western Oklahoma to the Canadian River. This region, although characterized by bunch grass, has many small areas where the soil, because of its heavy character or because of overgrazing, supports an almost pure short-grass cover.

[7]Baker, O. E. Graphic summary of American agriculture. Yearbook, U. S. Dept. Agriculture, 31, p. 433, 1921.

The moisture conditions in this association are much the same as in the grama and western-needle-grass association. The soils, however, are lighter in color, being more brown or chocolate-brown. The layer of carbonate accumulation lies at from 2 to 4 feet in depth and there is consequently no loss of water into the subsoil drainage. The quantity of stored soil moisture is greater here than in any other association considered and may be the equivalent of from 5 to 7 inches of rainfall. Rainfall throughout the year ranges from 25 to 30 inches. The growth season as determined by the length of the frost-free period ranges from 160 to 230 days and is rarely terminated by unfavorable temperature. As a rule growth ceases early in July when this grassland passes into a drought rest condition. Evaporation in this section is high, ranging between 40 and 50 inches.

The whole region is highly productive. Corn is important as a crop only in the northern part. The central and southern portion is the great winter-wheat area of the United States. In the extreme southern portion a large quantity of cotton is grown. The value of all crops is high over the whole area. It is good grazing land of high carrying capacity.

Sand-grass and sand-sage associes.—In regions lying in the central and south-central parts of the Great Plains area where the rainfall is low and the evaporation high, but where the soil is very light in texture, there occurs an associes very similar to the bluestem-bunch-grass association. Sand-grass (*Calamovilfa longifolia*), sand-sage (*Artemisia filifolia*), bluestem bunch-grass (*Andropogon scoparius*), and a large number of other grasses such as *Panicum virgatum*, *Sorghastrum nutans*, *Andropogon furcatus*, *Boutelouas*, and *Aristidas* characterize the area.

This associes represents an early stage of vegetation on sand hills which will give way gradually to bluestem bunch-grass when the soil has become stable and somewhat heavier in texture. The conditions here are not as favorable for plant growth as in the bluestem bunch-grass land, the soil being light, sandy and poor in nutrient material. Since the soil is loose and sparsely covered by vegetation it allows deep penetration of the rain water, some of which is lost to the subsoil, as is shown by the permanent streams which flow from such areas. The vegetation on this sand land continues to grow long after the plants on the adjacent hard land have dried out. In the sand hills of Nebraska and Colorado much of this land has come under cultivation. Fairly good crops of corn and sorghum are produced. Occasionally on the heavier land wheat is grown, but as a rule the danger of soil blowing is too great. These areas are principally valuable

for the production of forage. During the early days before the adjacent hard lands were occupied by farmers it was customary to save the sand-hills grazing for periods of snow falls when it was impossible to graze the short-grass on the adjacent hard lands.

Shinnery associes.—Although not differentiated on the map, most of the areas mapped as sand-grass and sand-sage which occur in Texas, New Mexico, and Oklahoma are characterized by a low oak (shin oak—*Quercus havardii*) about 18 inches high. It does not branch to any extent and is usually mixed with bluestem bunch-grass which is of about equal height. The soil is a light sand entirely unsuited for crop production.

Mesquite and Desert-grass Savanna.—This plant formation does not belong to the High Plains. We pass here to a short-grass cover over which are scattered small trees or thorn bushes. Both the begining and the end of the growth period are usually determined by available moisture. Temperature plays almost no part in limiting the growth of the natural vegetation. The distribution of water throughout the season is somewhat similar to that in the desert region. The rainfall is relatively heavy, but the high temperatures and the high saturation deficit of the air subject the plants to extreme drought conditions. There is a tendency over much of the area for the greatest rainfall to come in the spring and summer, during the period of greatest growth. Portions of the area have a rainfall of less than 20 inches, but in the eastern portion of the area it runs as high as 30 inches. Evaporation is high, from 45 to 70 inches.

This formation occurs in Texas south of the Canadian River and mostly south and east of the Plains border. It also extends over the lower southwest portion of the High Plains in Texas and southeastern New Mexico and also up the east side of the Pecos Valley.

Two divisions may be recognized within the area here considered:

Mesquite and mesquite-grass association;

Thorn bush and mesquite-grass associes.

In the eastern portion of this formation where the rainfall is relatively heavy, the trees large, and the grass cover rather dense, this type may be distinguished as the mesquite and mesquite-grass association. In the western portion of this formation the mesquite trees are small and there are many other small thorny trees and bushes which occur at intervals over an open grass cover. Much of the land is rough and broken and the vegetation partly in a developmental stage. This area may be designated the thorn-bush and mesquite-grass associes.

Mesquite and mesquite-grass association (Pl. VIIa.)—The mesquite and mesquite-grass association is one of the most distinctive types of

Texas vegetation. The trees may be either scattered or close together to form an open forest. They often give the appearance of an orchard of small fruit trees. Mesquite (*Prosopis juliflora*) is the dominant tree, although others occur. In many places, especially in the south and east, prickly pear (*Opuntia lindheimeri*) is almost as plentiful as mesquite. Grasses are abundant, chiefly curly mesquite (*Hilaria belangeri*), buffalo grass (*Bulbilis dactyloides*), and species of Aristida and Bouteloua. Mesquite is often damaged by drought.

In general appearance this association suggests an abundant water supply, followed by extreme drought. The soil is not deep, being only 1½ to 2 feet to the layer of carbonate accumulation. Although the rainfall is relatively heavy, 20 to 30 inches, it does not penetrate deeply into the soil and is rapidly absorbed and transpired by the growing plants.

This association forms a band about 200 miles wide extending from the Gulf of Mexico in the south to the Canadian River in the north. This band in the central portion is bent westward to Martin County, Texas.

The larger mesquite trees and much denser grass cover distinguish this association from the thorn-bush and mesquite-grass association. This is because the available moisture is greater in the mesquite and mesquite-grass area. On the north mesquite is apparently limited by low temperatures and on the east by the oak forests. Mesquite here grows on a dark soil with a layer of lime accumulation at about 2 feet. The oaks grow on sandier land of lighter color when the zone of carbonate accumulation has disappeared.

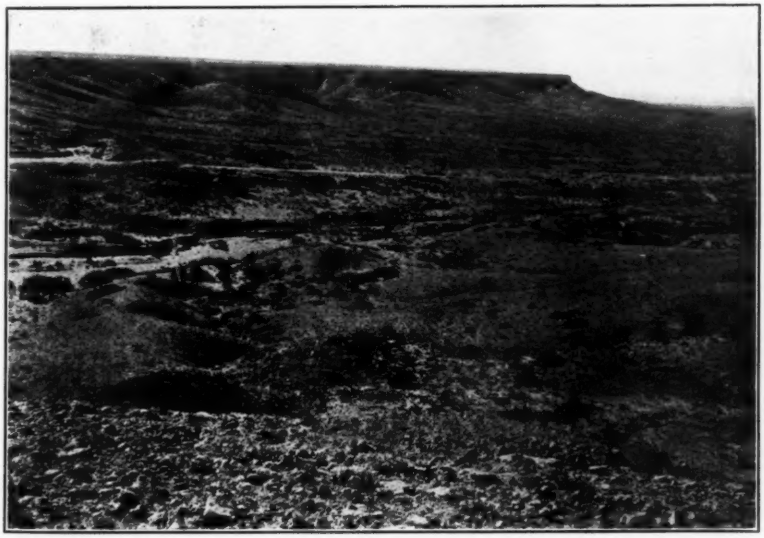
This area is suitable for grazing and the mesquite trees furnish both fence posts and fire wood. Much of this land has been put under cultivation. Cotton is the principal crop, although grain sorghums are important, especially in the north.

Thorn-bush and mesquite-grass associes (Pl. VIIb.)—In the thorn-bush and mesquite-grass associes mesquite and other thorn bushes and cacti are scattered over a sparse desert-grass cover. The soil is always visible because of the sparse vegetation.

The cover in this association is composed of curly mesquite (*Hilaria belangeri*), buffalo grass (*Bulbilis dactyloides*), species of Aristida, and other desert grasses. Mesquite trees (*Prosopis juliflora*) are scattered over this grass cover and with these are associated thorn bushes and cacti of various types.

This associes extends in a narrow strip from the Gulf of Mexico at the mouth of the Rio Grande River northwest to the southeast corner of New Mexico and across and up the southwest border of the High

a. Mesquite and mesquite grass association (mesquite and desert grass savanna). A good cover of *Hilaria belangeri*, *Bulbilis dactyloides* and a scattered growth of *Prosopis juliflora*. Haskel, Texas., Sept. 19, 1922.



b. Thorn brush and mesquite grass (mesquite and desert grass savanna). A scattered growth of mesquite and cat's claw and desert grasses on rough and broken land, east of Hagermann, New Mex., Nov. 30, 1920.

Plains. It also extends along the southeast border of the High Plains into Cottle and Motley counties, Texas. On the western edge this type passes either into southern desert shrub, in which case the grasses disappear and a shrubby, open growth takes its place, or into desert grassland, in which case the trees and shrubs disappear, leaving the grasses dominant.

The high water requirement in this hot climate and the long drought period make this type of doubtful agricultural value. Attempts have been made to grow cotton and grain sorghums in the better portions.

Sagebrush (Northern Desert Shrub).—The true sagebrush desert is not represented in the area here considered. There are, however, intrusions of the desert type on some of the poorer land of the northwest. These areas are largely the result of poor or alkali soils and more extreme climatic conditions. The most extensive areas occur on the heavy clay soils of Montana and Wyoming.

Sagebrush and western-wheat-grass associes (Pl. VIIIa.)—Where the short grasses drop out and the wheat-grass remains or is mixed with sagebrush, the soil is a heavy impermeable clay. There is alkali present in places but such areas are usually free from sagebrush which is replaced by saltbush. No continuous grass cover is formed on the breaks and clay flats. Such land is inferior to adjacent short-grass land for grazing land and is non-productive under cultivation.

Mesquite Grass (Desert Grassland).—Much of the area occupied by this formation lies outside of the region now being considered. Only a portion of the mesquite-grass formation occurring in eastern New Mexico and the eastern part of the Trans-Pecos region in Texas is included.

Black grama association (Pl. VIIIb.)—Black grama (*Bouteloua eriopoda*) characterizes the dry desert plains of west Texas and New Mexico. It does not form a sod but rather an open grass cover. Black grama is seldom an unmixed grassland, and there are often yucca, mesquite, and other desert shrubs scattered over the grass cover. The soil is shallow, often with carbonates at the surface. Rainfall usually starts growth during the summer when the temperature is high and evaporation rapid. Land of this character is valuable for grazing but is entirely unsuited to crop production without irrigation.

BRIEF GENERALIZATION.—In the area here considered the supply of rainfall is not sufficient to moisten the soil below the reach of the grass roots. No moisture is lost to the subsoil, and there is normally no storage of soil moisture from year to year. The subsoil is permanently dry. Over much of the area the soil is filled to its carrying

capacity only to a depth of 1 to 4 feet below the surface. This soil moisture is absorbed and passed out into the air by transpiration before the first frosts in autumn. The growth period is therefore initiated by favorable temperature but terminated by drought.

The total quantity of water stored at the beginning of the season is equivalent to from 2 to 5 inches of rainfall. To this initial supply must be added the rainfall during the growing season. This may vary from 2 to 15 inches.

The moisture supply is greater in the south than in the north, but the water requirement of the plants is proportionately greater. For the growing plant the moisture conditions are therefore similar.

The needle-grass and slender-wheat-grass area is one of rich, deep, black soil moistened to a depth of 2 to 3½ feet at the beginning of the growth period. The water requirement of plants is lower than in any other area of the region considered. The area produces a good stand of relatively tall grasses valuable for forage and native hay. The land, under cultivation, has become the great spring-wheat area of the United States.

South of the needle-grass and slender-wheat-grass area the bluestem-bunch-grass association characterizes a soil moist from 2 to 4 feet. A good growth of tall grass is produced, valuable both for pasturage and native hay. This association characterizes the great winter-wheat area of the United States. This area is also productive of corn and alfalfa.

South of the bluestem-bunch-grass area, the mesquite and mesquite-grass area is one of alternating severe drought and good moisture supply. The area is not as favorable for plant growth as those just mentioned. Cotton is produced throughout the area and grain sorghums are grown chiefly in the north.

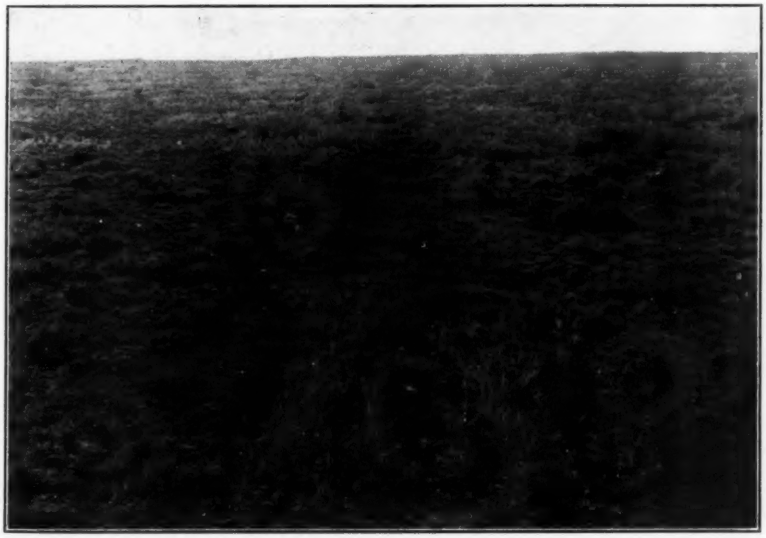
The groups of plant associations just considered represent land primarily valuable for crop production. Lying just west of this group of plant associations are the grama and western-needle-grass, the wire-grass, and the western-wheat-grass associations. Here crop failures are more likely to occur and agriculture rests both on crop production and grazing. Still farther west crops can only be produced during exceptionally good years, and the land is chiefly valuable for grazing.

On the basis of agricultural potentiality of the land the plant communities may be arranged as follows:

Land primarily valuable for crop production:

1. Needle grass and slender wheat-grass (spring wheat and other spring cereals)
2. Bluestem bunch-grass (winter wheat, corn, and alfalfa)
3. Mesquite and mesquite grass (cotton and grain sorghums)

a. Sage brush and western wheat-grass association (sagebrush). Wheat-grass alone or wheat-grass associated with sagebrush or other desert shrubs often occurs on land which is too poor to support grama grass. Thirty miles northeast of Roy, Mont., Sept. 22, 1917.



b. Black grama association (mesquite grass). Mostly *Bouteloua eripoda,* Aristidas and annual grasses. West of Roswell, New Mex., Dec. 4, 1917.

Land valuable for crop production and grazing: (crop failures during years of less than normal rainfall):

4. Grama and western-needle-grass (spring wheat and other spring grains)
5. Wire-grass (winter wheat, corn, and grain sorghums in the south)
6. Wheat-grass (spring grains and corn)
7. Grama and mountain sage (spring grains)

Land valuable for grazing and crop production: good crops only during years of more than normal rainfall):

8. Grama and buffalo-grass (grain sorghums, corn, and small grains)
9. Mesquite grass and thorn bush (cotton and grain sorghums during good years only)
10. Sand sage and sand grass (corn and sorghum except in the southwest)
11. Grama grass (spring grains during good years only)

Land valuable for grazing only:

12. Sagebrush and western wheat-grass
13. Black grama

Numbers 1, 2, 4 and 10 are best as hay land. As grazing land the numbers would run about as follows: 1, 2, 6, 4, 5, 10, 7, 8, 3, 11, 9, 13, 12.